GROUNDWATER ASSESSMENT AND WATER QUALITY STATUS IN PARTS OF YAMUNA RIVER SUB-BASIN OF ALIGARH-MATHURA DISTRICTS, U.P., INDIA

ABSTRACT

THESIS
SUBMITTED FOR THE DEGREE OF
Doctor of Philosophy
IN
GEOLOGY

BY
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DEPARTMENT OF GEOLOGY
ALIGARH MUSLIM UNIVERSITY
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ABSTRACT

Water is prime natural resource and a basic human need. Groundwater is a major source of water for drinking, industrial, and for irrigational purposes. The water demand is to increase many folds with the rising population, expanding agriculture and escalating industrialization with the passage of time.

The Yamuna-Karwan sub-basin forms a logical unit for hydrogeological investigations. It is bounded by two natural hydroboundaries, the river Yamuna in the west and river Karwan in the east. The study area represents a combination of two extreme hydrogeological situations that is one of water logging and the other of aquifer depletion, and hence it was selected as an ideal area for the investigation. The study covers an area of about 1033 sq. kms. It lies between the latitudes 27°25'24" and 29°18'27"N and the longitudes 77°30' and 78°46'15"E.

In the present investigation an attempt is made to depict a comprehensive and balance picture of the aquifer systems, their geometry, quantum of water resources and their quality. In addition to these, occurrence, movement and behaviour of the water level fluctuations in time and space is also studied by the systematic groundwater surveys of 93 dugwells supported by laboratory investigations.

Physiographically, the area is divisible into two distinct physiographic units namely, Karwan-Patwah tract

and Yamuna-Patwah tract. It is drained by Yamuna and Karwan rivers which flow due south. Mat branch feeder canal has its own importance in the area.

The area falls under the sub-tropical zone marked by chilly winters followed by extremely hot summer with an average mean rainfall of 693.74 mm.

Geologically, the area is underlain by Quaternary alluvium, comprising clay, silt, and sands of various grades intermixed with occasional beds of calc-concretion. This Quaternary alluvium unconformably overlies the Neogene Siwaliks, which inturn overlies the eroded and upturned surface of Upper Proterozoic Vindhyans. Furtherdown, the Upper Vindhyan overlies the Bundelkhand granitic massif of Archean age which forms the basement.

The fence diagram and various hydrogeological cross-sections depict that there occur three to two tier aquifer systems down to the depth of 92 m.b.g.l. which merge with each other and behave as a single bodied aquifer system. The beds are generally lenticular and there are rapid alternation and gradation between granular and clayey materials particularly in western part.

The near surface groundwater occurs under water table condition and depth to water level varies between 1.20 to 19.0 m.b.g.l. during pre-monsoon and 0.78 to 18.30 m.b.g.l. during post-monsoon periods.

The water level is deep in upland area i.e. recharge area and shallow in low lying area, discharge area. Shallow water levels are mainly observed along the

Mat branch feeder canal. The water level fluctuation map revealed a rising trend along the canal due to excessive quantum of seepage through unlined canal beds. The fluctuation ranges between 0.5 to 1.5 meter.

The altitude of water table in the sub-basin ranges from 190 meter in northwest to 162 meter in the southeast above the mean sea level. Regional groundwater flow is from NW to SE direction in consonance with the topography of the area with some variations due to local factors. The hydraulic gradient varies from 0.50 to 2.5 m/km. The contours behaviour show that the rivers Yamuna and Karwan are effluent in nature except at two places where Yamuna river is influent due to heavy withdrawl of water. The hydrographs of the key observation wells show the water level variation is cyclic and sinuosoidal as a function of time and space.

The pumping test data and analyses reveal that the transmissivity and storativity values determined are 503 m^2/day and 1.34×10^{-4}, respectively. The hydraulic conductivity value is determined as 18.64 m/day. Further results indicate that the aquifer tapped is confined in nature. The hydraulic conductivity values determined through grain size analysis of aquifer material ranges between 25.40 to 132.71 m/day.

The water balance studies indicate availability of surplus groundwater resources as 14542.04 ham. with only 50.81% groundwater development in the study area, capable of supporting additional 100 deep tubewells and about 1000 shallow tubewells in phases over a period of five years.

The results of chemical analysis data show that the groundwater in the area is potable, hard, alkaline in reaction, moderately mineralised and alkali bicarbonate type. The values of cations and anions are found well within the standard limits except slightly higher (1.89 ppm) fluoride content in shallow groundwater in Nojhil block.

Trace elements studies reveal that the concentration of heavy toxic metals (Fe, Cr, Pb and Cd) in the shallow aquifers is more than the permissible limits which may entail various health hazards to the users. However, the concentration of these toxic metals are generally found well within their permissible limits in deeper aquifer water samples. Moreover, the analytical data is compared with the various water quality criteria and accordingly the groundwater of the area is found suitable for drinking and irrigational purposes.

Surface water samples analysis reveal that the concentration of major ions are generally lower than the groundwater. However, the concentration of trace elements (Fe, Cd, Pb & Mn) in water samples of Yamuna river is much than their standard limits. The higher concentration of these heavy metals may be attributed to the Delhi metropolis effluents.

Environmental hazards observed in the area are soil salinization, water logging and human interference with the nature posing a threat to ecological balance of the study area.

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1993

To

My Parents

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Dr. Shadab Khurshid
Reader & Deputy Co-ordinator
(DSA Programme)

ENVIRON/HYDRO LAB
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Aligarh-202 002 (INDIA)

CERTIFICATE

This is to certify that **Mr. Nurul Hasan** has completed his research assignment entitled **"Groundwater Assessment and Water Quality Status in Parts of Yamuna River Sub-basin of Aligarh-Mathura Districts, U.P., India"** under my supervision in the field of Hydrogeology/Environmental Geology. The work is being submitted for the award of the degree of Doctor of Philosophy of the Aligarh Muslim University, Aligarh in Geology.

The work is an original contribution to the existing knowledge of the subject. Mr. Hasan is, therefore, allowed to submit the same in the form of a thesis for the award of the Ph.D. degree of the Aligarh Muslim University, Aligarh.

S. Khurshid

(DR. SHADAB KHURSHID)
Reader

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N. Hasan

[NURUL HASAN]

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CHAPTER - I
INTRODUCTION

INTRODUCTION

In the holy books, water is described as a source of life on the earth. The water covers 71% of the earth's surface. Out of the total volume of water on the earth, 97.2% is saline water 2.14% occurs as ice caps and glaciers and 0.61% as groundwater and 0.001% as freshwater in rivers and lakes (Fetter, 1980). This shows that freshwater which is one of the basic necessities for sustenance of life is a very rare commodity particularly so in view of the rising population, extensive agricultural and industrial activities. Human race through the ages has striven to locate and develop it. Over 90% of liquid freshwater available at any moment on the earth lies beneath the land surface. At the present rate of consumption it will not be too long, before freshwater become the limiting factor, in biological, economic and social growth through out the earth. This has necessitated a detailed appraisal of fresh water resources all over the world. The national and international policies on exploration, exploitation and management of water resources have been evolved in order to facilitate its equitable distribution.

India has been bestowed with substantial water resources. So far the principal consumptive use of water has been for irrigation. Demand of various other sectors like domestic and industrial water supply has been growing rapidly and it is expected that by the year 2025 A.D. the utilisable water resources of the country may be almost fully utilised. Water by itself is a replenishible national resource, hence development of this vital resource is important in any society, but is even more so in India in

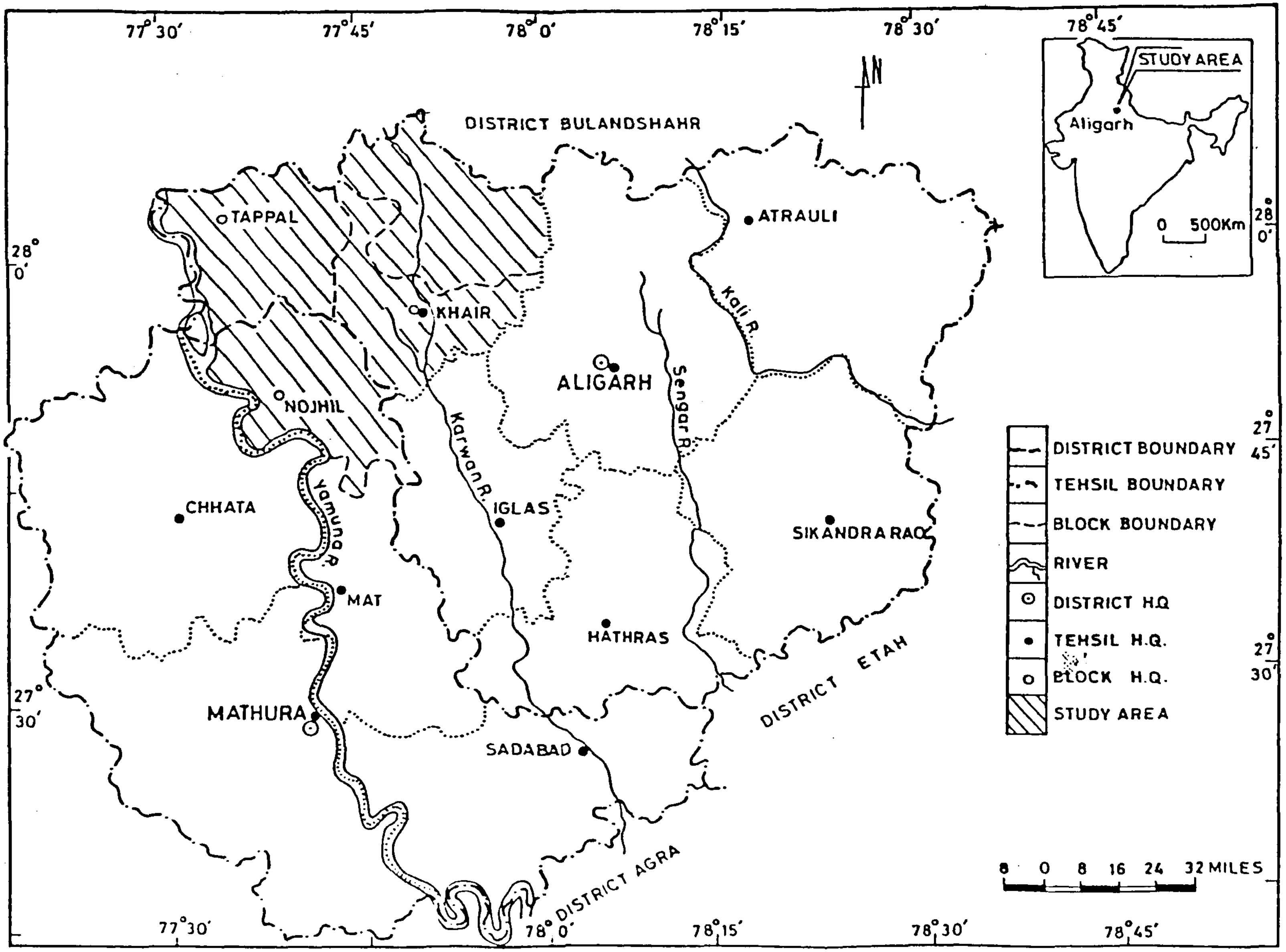


Fig. 1.1: Map showing location of the study area.

view of the arid climate and agrarian economy. Prompted by unprecedented drought and floods in different parts of the country, various efforts in this direction have been initiated by the government (Ramesam, 1989).

The physiographic features, climatic conditions and nature of soils control the groundwater resources which play a significant role in determining the groundwater resources and its development. Since the demands of water for various purposes is increasing day by day. It is, therefore, imperative that study and planning of water resources should start in terms of river basin or sub-basin as far as water resources development is concerned.

In persuance of the above, the present investigation was carried out in Yamuna-Karwan sub-basin as part of Ph.D. programme, which forms part of the Central Ganga basin (Fig. 1.1). The study comprised evaluation of the aquifer systems, their geometry and groundwater resource potential and water quality in parts of Yamuna-Karwan river sub-basin of Aligarh-Mathura districts. The quantified data base thus generated for the sub-basin will provide basic data for the planning and hydrogeological management of the basin.

1.1 LOCATION OF THE STUDY AREA:

The study area forms a part of Ganga-Yamuna Doab of Central Ganga plain. The Ganga basin forms a prominent physiographic unit of India.

The area is located in the semi-arid ecosystem of Central Ganga alluvium plain. Geomorphologically, it occupies the interfluves between the Ganga and Yamuna flood plains. The Yamuna and Karwan rivers form the western and eastern limits of the area, respectively. It falls in the survey of India toposheet Nos. 53E and 54I, covering an area of 1033.01 sq. km. and lies between latitudes 27°25'24"N to 29°18'27"N and longitudes 77°30'0"E to 78°46'15"E.

The area is well connected by metal roads from Aligarh and Mathura towns. Almost all villages are approachable by motorable roads. Khair, Tappal and Nojhil are important small towns in the study area with suitable camping facilities.

1.2 STATEMENT OF THE PROBLEM:

The choice of the area was made due to its representative character. The sub-basin presents a dual situation that is one of lowering of water table in some parts and rising water level leading to water logging and soil salinisation in canal command areas.

Systematic hydrogeological surveys were carried out in order to delineate the aquifer systems and their lateral and vertical extents, water resources and their quality.

Yamuna-Karwan sub-basin is rich in groundwater potential which over the years has witnessed phenomenal increase in the numbers of shallow farmer's tubewells and state tubewells to meet the ever increasing water needs. In order to increase the irrigation facilities the Government of Uttar Pradesh has introduced the canal system, so this area has wide network of canals.

1.3 AIMS AND OBJECTIVES:

The present study has been carried out in order to cover the different aspects of the development and management of groundwater potential as well as water quality status in the area with a view to:-

i) Define major water bearing zones.
ii) Define location, extent and inter-relationship of aquifers.
iii) Establish hydrological parameters of aquifers like transmissivity, storativity and hydraulic conductivity.
iv) Study the movement of groundwater and behaviour of water level in time and space.
v) Delineate areas of groundwater recharge and discharge.
vi) Study the hydrochemistry of groundwater and surface water bodies in the area.
vii) Evaluate the groundwater resources of the basin and to demarcate areas for further groundwater development.

1.4 METHODOLOGY:

In order to generate quantitative data based on hydrogeological and hydrochemical parameters, systematic groundwater surveys have been carried out to cover the different aspects of the development and management of groundwater resource potential followed by laboratory investigations.

i) The available hydrogeological informations from the published literature and unpublished reports of

Geological Survey of India, Central Groundwater Board (C.G.W.B.) and State Groundwater Department, were collected and studied.

ii) Concerned toposheets were used to prepare the base map for the study area.

iii) Rainfall data were collected, processed and plotted. The rainfall data were analysed and the mean, standard deviation, coefficient of variation, occurrence and frequency of droughts were determined for the period of 1901 to 1993.

iv) In order to generate hydrogeological data base a network of 93 observation wells was established. The wells were evenly spaced covering the entire area and groundwater samples were collected from the observation well and other groundwater structures such as shallow and deep tubewells. Besides, water samples from canals and rivers draining the area were also collected and analysed.

v) Repeat measurements to monitor the changes in water level, for pre and post-monsoon water level were taken during 1992 and 1993.

vi) The aquifer material (sand samples) were collected from various drilling sites and also from the rivers Yamuna-Karwan beds through trenching. The aquifer material and river sands samples were mechanically analysed and data obtained were plotted on the grading curves. Various parameters like effective grain size, uniformity coefficient and hydraulic conductivity were determined.

vii) Pumping tests were conducted at Sopha and Makhdumpur villages to determine the aquifer characteristics i.e. storativity, hydraulic conductivity and transmissivity.

viii) Lithological logs of deep tubewells in the area were collected and fence diagram and hydrogeological cross-sections were prepared.

ix) The hydrogeological data of dugwells were processed, plotted and interpreted. Various pre and post-monsoon depth to water, water table contour and water level fluctuation maps were prepared. Hydrographs for a period of 10 years were prepared to analyse the changes in the groundwater regime in time and space.

x) Groundwater balance studies were carriedout to evaluate the utilisable groundwater resource potential for future development in a phased manner.

xi) Water samples were analysed for major and trace elements to determine its quality for domestic and irrigation uses and in order to determine the vertical and lateral variation in water quality. Various hydrochemical facies were determined through plotting of chemical data on trilinear diagram.

xii) Concurrence and synthesis of hydrogeological, hydrological, hydrometeorological, hydromorphological and hydrochemical data have been attempted to generate the model for groundwater regime of Yamuna-Karwan sub-basin presented in the present thesis.

1.5 STATE OF ART:

The series of developments in hydrogeology between

1856 and 1955 helped to establish the prinicple of groundwater resource evaluation.

Darcy (1856) did experimental work on the flow of water in sand and derived the formula known as Darcy's Law, which expresses the relationship between the velocity of percolation, permeability of water yielding material and hydraulic gradient. Darcy's Law serves as the basis for subsequent attempt on quantification of groundwater resource.

Thiem (1906) developed an equation for steady state flow conditions of groundwater. Theis (1935) gave the non-equilibrium formula for unsteady state flow to a well dischargging from a confined aquifer. Several workers since then have formulated equations relating to discharge from an aquifer to the head difference under the different conditions like leakage from the overlying aquitard, delayed yield, large diameter wells, multiaquifer system etc. (Jacob, 1946; Boulton, 1963; Huntush, 1956; Walton, 1962; Pricket, 1965).

The last three decades have seen phenomenal growth in the science of hydrogeology. It is now not limited to resource aspects and hydrodynamics but encompasses physico-chemical relations and responses, occurrences, movement and energy storage in the aquifers. Besides the resource potential, the area is looked into its entire verticle profile from atmosphere to lithosphere (Ramesam, 1987).

Development of information system and computerized groundwater data bases with telemetric link to ground instruments on real time basis, studies on recycling of resource, krigging techniques for evaluating regional variable out of spare data and groundwater modelling using finite difference and finite element models to solve groundwater flow and solute transport problems etc. are some of the modern fields in groundwater research (Marsily, 1986; Bear, 1987).

Systematic groundwater exploration was taken up in early fifties by the Central Groundwater Board, in India was initially confined to resource evaluation in the unconsolidated formations. The activity extended to the hard rock regions about 20 years latter. The techniques of exploration primarily consisted of geological, reconnaissance, occasional geophysical survey and actual drilling. Today resource estimation at micro-level for some of the river basins through water budgeting studies are available (Ramesam, 1987).

Co-incidental with the water balance studies a few research project of specific nature problems have been undertaken. In recent years monitoring of the effects of the withdrawals on the groundwater levels and regional decline in water levels has been gaining importance (Rao, 1986).

A concerted thrust on Research and Development in Groundwater with identified areas of research duly supported by requisite budget allocations, however, has been lacking in India. As the country is marching towards 21st Century by which time the total annual replenishible recharge from rains to groundwater body would ahve been fully utilized, the conservation of existing finite resource, its augmentation, protection and judicious exploitation would require an urgent attention.

1.6 PREVIOUS WORK:

Various agencies had undertaken hydrogeological investigations of the Ganga basin for different purposes.

The first 'Irrigation Commission' in 1903 affirmed the importance of groundwater for irrigation and consequently in 1934 a project for construction of 1500 community tubewells in the Ganga basin was initiated in Uttar Pradesh.

In the year, 1935, Taylor carried out statistical analysis of the rainfall and spring level data in Meerut division as well as in the other parts of the Ganga basin in Uttar Pradesh. He conducted field experiments to study the transmitting capacities of the water bearing formations in selective regions of Ganga basin and came to conclusion that in this alluvial tract, the tubewells of 1.5 cusecs capacity spaced a mile to one and half mile apart can safely be operated without any appreciable depletion in regional water table.

Auden (1936) submitted to the U.P. government,number of technical reports related to groundwater occurrence and suitability for sinking tubewells in Gangetic alluvial tract of Uttar Pradesh.

the Exploratory Tubewell Organisation (ETO) was set up during 1954 under Indo-US technical co-operation. In October, 1970 the Ministry of Agriculture merged ETO with the groundwater wing of the Geological Survey of India which led to the birth of the Central Groundwater Board (CGWB), which is an apex body responsible for the exploration, assessment, development, management and regulation of the groundwater resources in India.

Later on, the officers of the C.G.W.B. (Mathur, 1958; Shah, 1960; Dubey; 1961; and Pathak, 1961) carriedout groundwater investigations and evaluation of the resources potential in parts of Yamuna-Karwan sub-basin.

Dutt (1969) studied the hydrogeology and water-logging conditions in Aligarh district. He reported that the seepage from canals has created water logging conditions in the canal command areas.

Ahmad on 19th June, 1976 established for the first time, the depth to bedrock near Aligarh railway function in the district Aligarh. According to the exploration report the thickness of alluvium overlying the Upper Vindhyan red shale was recorded as 340 meters below ground level.

Sahni and Garg (1981) demarcated the saline zones in Mathura district.

Khan and Nigam (1986) worked on geology and geomorphology of the sub-basin and reported that the basin is probably carved out of Vindhyans basement floor.

Verma (1989) found out the saline water zone in parts of Aligarh and Mathura district and concluded that the fresh water is floating over the saline water in Nojhil block. Rastogi and Gaumat (1990) worked on groundwater pollution in Mathura district and reported higher concentration of lead, iron and fluoride at some places.

Besides, Irrigation Research Institute (I.R.I.) Roorkee, Central Groundwater Board, Minor Irrigation Department (U.P.) and State Groundwater Department are engaged in surface as well as groundwater studies of the alluvial tract of Ganga and Yamuna rivers. National Institute of Hydrology, Roorkee is also actively engaged in hydrological studies in various parts of Central Ganga plain.

CHAPTER - II

PHYSIOGRAPHY AND DRAINAGE

PHYSIOGRAPHY AND DRAINAGE

2.1 PHYSIOGRAPHY

The are[illegible] [illegible]r investigation [illegible] parts of Aligarh and Mathura districts of western Uttar Pradesh and lies in the upper Doab of Ganga and Yamuna rivers. The western [illegible] by the Yamuna river, and the eastern [illegible] by the [illegible] river.

Physiographically, the study area is a plain of remarkable fertility sloping gently from north to south and south-east. [illegible] surface has [illegible] master slope towards south east with gradient 0.25 m/km. Logitudinally, the level surface is varied by several depressions, formed by the river valleys and natural drainage lines, while the elevations consists merely of slight ridges of sand, which intially appear to have been due to fluvial action. The most prominent of these ridges are to be found in Khair tehsil in the north west, where three irregular lines extend from north to south. The first follows the boundary between the Tappal and Chandaus blocks, the second is tracable along the right bank of Karwan river and the third, more interrupted and less clearly defined than the others, lies few kilometers to the east.

Physiographically, the study area is divisible into two distinct subdivisions:

1. Karwan-Patwah tract
2. Patwah-Yamuna tract

Karwan-Patwah Tract:

This tract which lies between the Karwan river and Patwah nala (drain) extends in the north-west to south-east direction. In the upper course, it contains a broad basin with low-lands on both sides. The general characteristics of this trace are maintained, loam alternating with clay. these are variations in general level of the country are those formed by the minute valley of the Karwan and the lines of the sand hills. The general slope of the area is regular. The maximum height of the ground surface is about 640 feet above sea level at Tappal in the north-west dropping to 221 feet on the bank of [illegible] Karwan near Khair. The soil of this physiographic unit is alluvium comprising fine through medium to coarse sand. The soil profile is mature and deep and the entire area shows an upland topography. The slope in the region varies from 1% to 3%, and erosion ranges from slight to moderate. Geomorphologically, this tract consists of numerous point bar deposits with enechelon distribution. Each point bar deposit consists of coarsest material at bottom and the finest at the top thus it represents a fining upward sequence. Eolian sand mounds and ridges are arranged in a linear fashion in north west southeast direction, showing a change in wind direction.

Patwah-Yamuna Tract ([illegible] r)

This tract lies between the Patwah drain and Yamuna river with a varying width from 10 km. in the north to about 8.20 km in the south. The soil of this tract is richer has sandy character. The entire area is gently undulating flat alluvial surface ranging in elevation from 192-171 m above m.s.l. with a south-easterly master slope.

Sand mounds and ridges are developed on this flat alluvial surface as discontinuous patches and characteristically rise 2-5 m above the general ground level (Plate-I).

This tract is characterised by clayey to sandy soil, imperfect natural drainage and numerous lakes in which the surface water collects without finding an adequate outlet. In consequence of the resultant saturation the fertility of the soil is marred by frequent stretches of salt encrustations.

2.2 GEOMORPHOLOGY OF THE AREA:

The area is classified into three main geomorphic units based on the criteria of relief, lithology, soil, vegetation, drainage and land use of different morpho-units.

i) Eolian Sand Surface
ii) Yamuna Alluvial Plain
iii) Yamuna Flood Plain

i) *Eolian Sand Surface:*

Isolated clusters of sand mounds and ridges running from north western part of the area (north of Khair 54E/13), towards south east upto the southern margin near Chandapha, are found and has been designated as eolian sand mounds and ridges (Plate-I).

These dunal features are about 2-5 m. high above the general ground level and can be best studied west of Khera village, Bhamrola, Bazidpur, Bhanera, Patwa nagla and Bhojgarhi etc.

PLATE-I

Sand dunes with plane, east of river Yamuna.

Generally, longitudinal and oblique type of dunes can be recognised on the visual estimate in field. But due to human interferance it is difficult to recognize their dunal shape types in the area. Moreover, the inflow of sand also seems to be stopped and new sandy features are not made. Recent major shifting of these sandy features are not noticed in the area. The windward side in general was towards east and north east, hence it is inferred that these dunal features are aligned NW-SE and E-W direction. NE-SW dunal features are also noticed in the area. These dunal features are devoid of natural vegetation except some thorny bushes and long grass (Plate-II).

ii) *Yamuna Alluvial Plain:*

The alluvial plain of the study area exhibits nearly homogeneous landscape. The monotony is locally punctuated by selected land use. The raised level of ground reaching to an elevation upto 204 m above m.s.l. have been used for habitation purposes. The lower depressed plains possibly representing scars of paleodrainage (Plate-III), are characterised by extensive agricultural activity and spatial disposition of wells and tubewells. The alluvial plain is characterised by paucity of well developed surface drainage. The slope characteristics are predominantly within the range of gentle (1-10°). Locally the slope becomes moderate (10-20°). The erosion is generally controlled by sheet wash which has erased the landscape in homogeneties carved by fluvial dynamics of the Yamuna river during the geomorphic evolution of the area.

The fluvial features associated with this surface comprise palaeochannels, tals (natural relict of fluvial

PLATE-II

A view of general level expense, east of river Yamuna.

PLATE-III

Yamuna Alluvial plain with rising level than the active channel.

PLATE - IV

Marshy land with characteristic meter long Typha grass.

depressions), cut-off meander scars are present in contrast to present day active channels forming a distinct geomorphic element in the area. This surface from the flood plain of the river about 2-5 m higher than the active channels and represents deposits of post-phase of the Yamuna. This surface shows extensive vegetation and number of marshy tracts (Plate-IV).

iii) *Yamuna Flood Plain:*

The area lying on the right and left banks of the Yamuna river has been delineated as geomorphic flood plain of the river (Plate-V). Yamuna flood plain is characterised by heterogeneity of land forms (Plate-VI). The surface representing dominantly depositional land-scape characterised by development of shawles and ridges in the sinuous zones of the river segment. At several places partially filled palaeochannels have been recorded. Depending upon their spatial distribution the land use practices has been introduced in the flood plain zones selectively along the filled up stretches of the palaeochannels. Locally, ridges and point bars in the flood plain have been used for development of habitation centres.

This surface is an upland surface characterised by overbank sand deposits capped by fine silt very often interclated with the calcareous concretions of varying sizes. there are many abondoned drainage and abondoned channels which have been given rise to numerous lakes and marshy lands in this belt.

Mukherji (1963) pointed out from his study of the Ganga-Yamuna interfluves that the palaeo-Yamuna river was characterised by 8-15 km wide broad river valley as

PLATE-V

Yamuna flood plain.

River Yamuna and dry channel during summer.

PLATE-VI

High bank and sloping planes of river Yamuna.

PLATE-VII A

River Yamuna during lean period.

PLATE-VIIB

Midial point bar in river Yamuna and dirty water (an index of pollution).

PLATE-VIIC

Two level land surface (T_1 & T_0 surfaces)

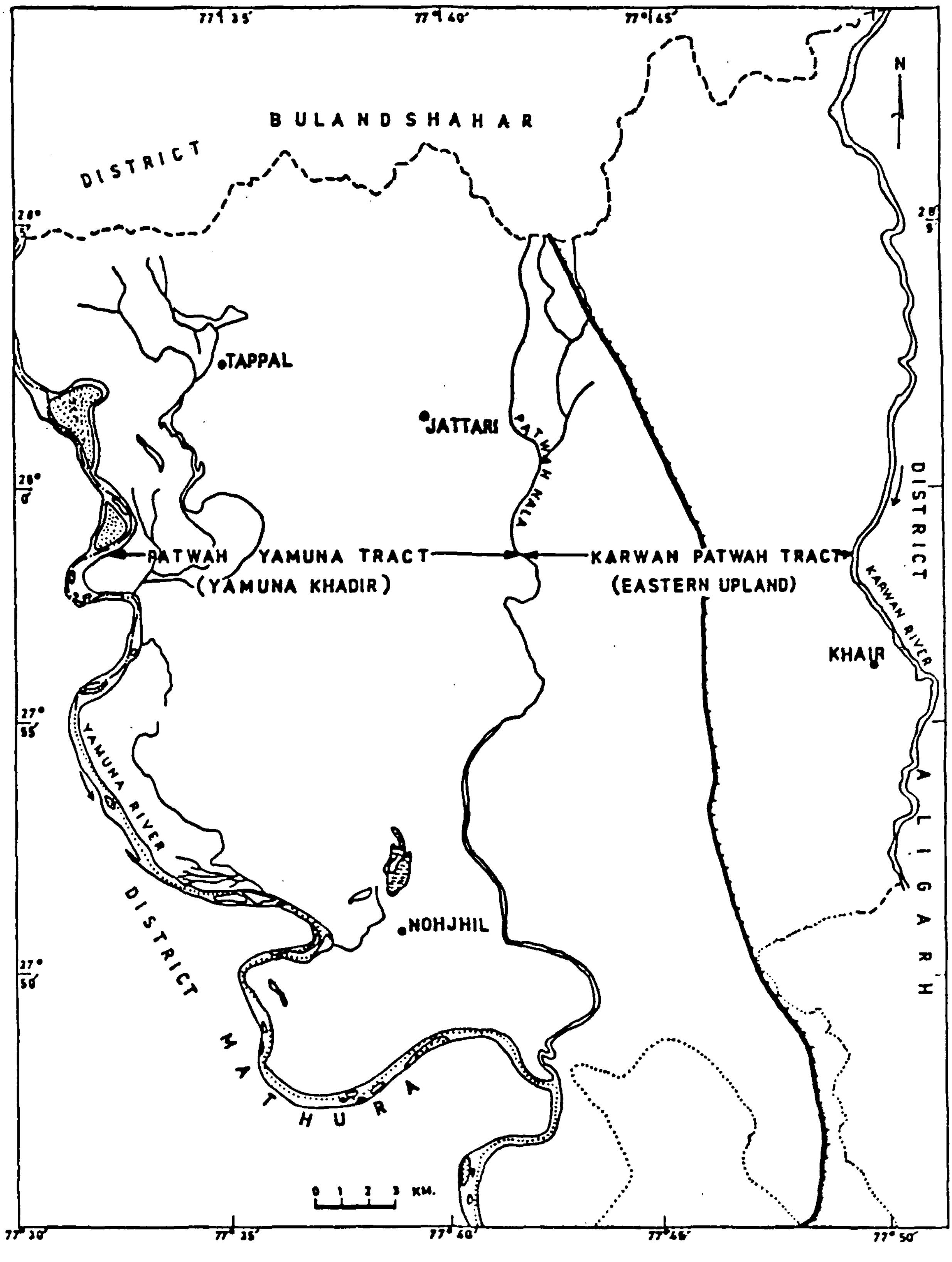


Fig. 2.1: Showing the physiographic divisions and drainage of the study area.

compared to the present day 3-10 km narrow flood plain. This means that in earlier phase the Yamuna river was much larger and carrying very higher discharges. During the last hundred years the Yamuna river under went a distinct change from meandering type to the present day braided type consequent to the decrease in water budget and increase in sediment load (Singh, 1990). The main factor leading to fall in discharge was the construction of barrage at Tajewala where from the eastern and western Yamuna canals emerge leaving not a single drop of water in the channel on the downstream side of the barrage. The diversion of this discharge of Yamuna water through canal is bound to have its impact on the river flow. The river regenerates its flow through the groundwater, runoff from the banks and discharges from the canal seepages till reaches Sonepat. At Sonepat it receives large amount of industrial and domestic effluents and then it traverses downstream and touches national capital Delhi to receive huge heap of domestic effluents before it is barraged at Okhla to meet the water demand of Delhi. A little amount of water is left in the channel on the downstream side to flow due south and form the western boundary of the study area about 65 kms from Delhi.

2.3 DRAINAGE:

The study area is drained by the Yamuna and Karwan rivers and the Patwah drain (Fig. 2.1). The Yamuna affects only the strip of Khadir lying below the old high bank. Its variations are very much less extensive than those of the Ganges, for the actual stream has a well-defined bank, which is topped only in years of unusually heavy floods.

PLATE-VIII

Revinous bank of river Yamuna near Sultanpur village.

PLATE-IX

Channel of river Yamuna during summer period.

The Yamuna River:

The Yamuna is one of the most important tributary of the Ganga river. it rises from Yamunotri off Banderpunch glacier at an elevation of 6330 m. above m.s.l. in Tehri Garhwal district of Uttar Pradesh in the Himalayas. Many small streams like Rishi Ganga, the Uma, the Hanuman Ganga and several others join it in the mountains. The Tons, the longest tributary, rises at an elevation of 3900 m and joins Ymuna below Kalsi. The Giri river rises near Simla and joins Yamuna near Paonta. The Yamuna enters the plain at Tajewala from it flows due south and joins the Ganga at Allahabad. In Tappal, Yamuna flows from north to south with meandering loop. the neighbouring lands along it are flat and low-lying plains and rise gradually with a gentle slope (Plate-VII). The width of the river at Tappal varies from about 390 meter during the rainy season to 150 meter in summer months. Similarly, the velocity of the river also varies from about 3 km/hour during normal season to 11 kms/ hour in the rainy season.

The floods in the low valley of the Yamuna are common and of long continuance, while the lands in its neighbourhood are liable to form revines (Plate-VIII). The river Yamuna is gradually shifting from its original course towards east (Plate-IX).

Karwan River:

The Karwan river, which forms the eastern hydro-boundary of the area, is a natural water course which rises in the north of the Bulandshahar district, and flows in a southerly direction through the Chandaus, Khair, Hasangarh, Gorai and Mursan, subsequently passing through the Sadabad

PLATE-X

A view of Karwan river flowing under bridge near Khair.

PLATE-XI

A part of Patwah drain near Bajna.

tehsil of Mathura to join the Yamuna river at Shahdara, close to the city of Agra. In the Khair tehsil it has a broad basin with low-lands on both sides. In the lower course, it follows a narrow sandy and well defined bed. (Plate-X). In summer it remains dry but during rainy season it attains a width of about 50 meters and a mean depth of about 240 cms.

Patwah Nala:

Between the Karwan and the Yamuna rivers there is small drainage channel in the study area known as Patwah Nala or Patwah drain. This begins in the Meerut district, but at first is a mere series of depressions and swamps, its progress being interrupted in places by undulations in the surface and also by canals and artificial drains. Before leaving Bulandshahar, however, it has assumed a definite channel, which has been artifically deepened, and thereafter it increases in size till it joins the Yamuna at Nojhil. In the Khair area its course runs almost direct from Moron in the north to Salpur on the southern border of Tappal and it is reinforced by one or two minor drainage channels, both natural and artificial (Plate-XI). These old drainage channels are most probably the erstwhile channels of river Yamuna itself, which it abundant with the passage of time while migrating from east due west.

2.4 CLIMATE AND RAINFALL:

The study area falls under the sub-tropical climatic zone and experiences extreme weather conditions characterised by extremely hot summer and severly cold winters. It is associated with a general prevalence of continental air current which moves from west-south west to east-north east.

Winter starts at the end of October and continues till the end of February when the day temperature starts rising. December and January are the coldest months. The maximum temperature during winter months is around 21°C and minimum around 4° to 9°C.

From mid March onwards the hot season starts and lasts upto the end of June. The maximum temperature upto 42°C and it often rises upto 45°C during June. Strong wasterly hot winds blow through out the day with dust storms occurring quite frequently.

Rainfall:

Monsoon breaks by 2nd week of June and lasts till the end of September. About 90% of the rainfall takes place during the months of July and August. Heavy down pours in one day are not uncommon while there may be long breaks with completely rainless days during this period. The rest of the year is dry except for occasional light showers during winters. The average annual rainfall of the study area is 693.74 mm.

2.5 AREAL DISTRIBUTION OF RAINFALL:

Areal distribution of the average annual rainfall in the study area is shown in the isohyetal map (Figs. 2.2a,b&c). A perusal of these maps shows that the intensity of rainfall decreases from east to west and on an average the eastern part of district receives more rainfall which gradually decreases in the west proximal to the bank of river Yamuna.

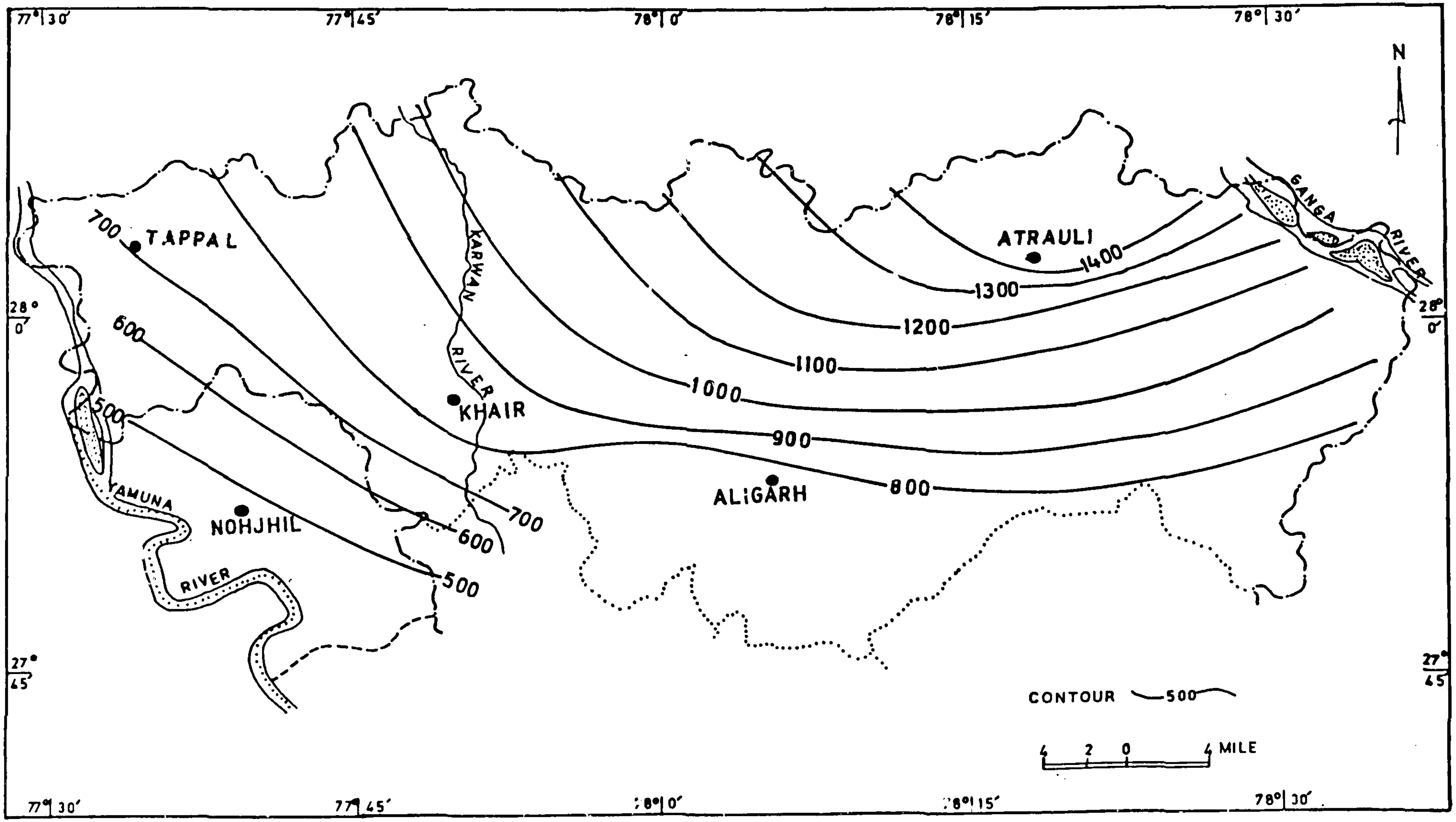


Fig. 2.2a: Isohyetal map of the study area (year 1992).

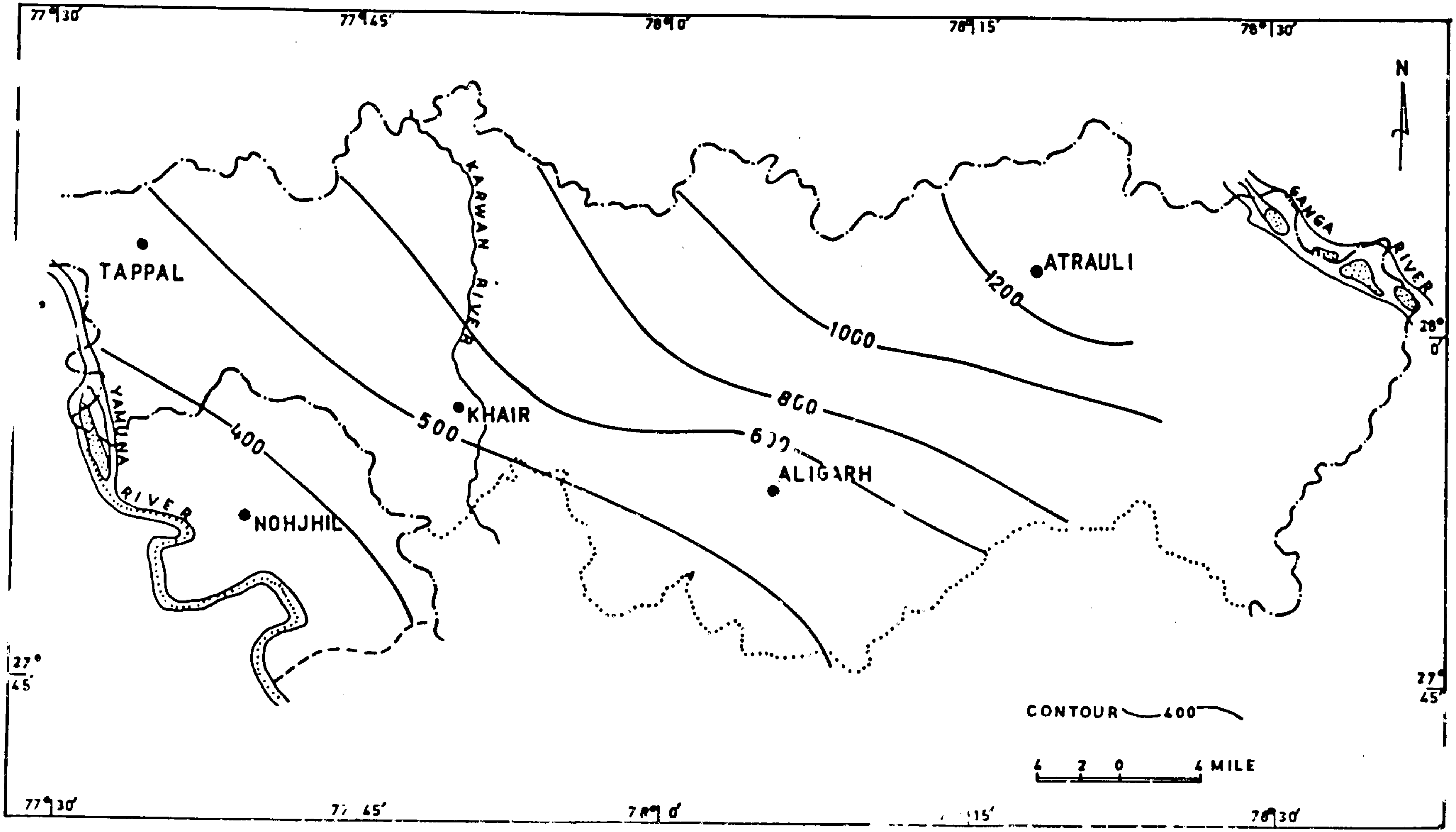


Fig. 2.2b Isohyetal map of the study area (year 1993).

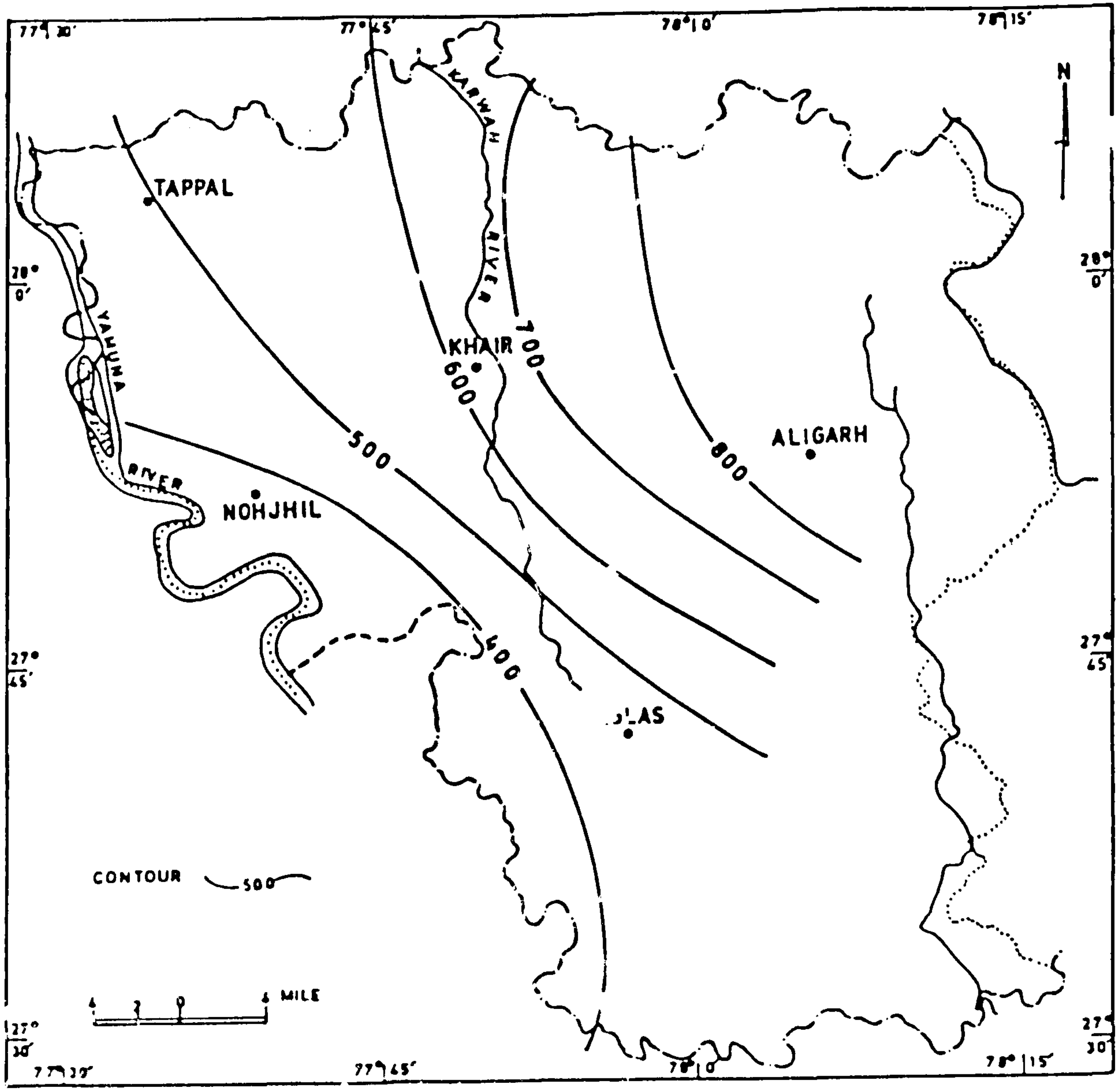


Fig. 2.2c: Ischyetal map of the study area (Average 1983-93).

Departures:

The departure and cummulative departures from the mean annual rainfall are given in (Appendix IA & IB) and are shown in (Fig. 2.3a& 2.3b and 2.4a & b). The departures show wide variation from the mean, indicating the erractic nature of the rainfall whereas cummulative departures ends around the mean annual rainfall reflecting a cummulative compensating effect as far as the quantum of excess and deficient rainfall over a larger period are concerned.

Variability of Rainfall:

The available annual rainfall data of Khair and Nojhil (Mat) raingauge stations for the period from 1901 to 1993 have been statistically analysed and results are tabulated (Table 2.1). The table shows that the highest rainfall at Khair rain gauge station is 1242 mm (1972) whereas lowest recorded 361 mm (1957) and at Nojhil (Mat) the highest rainfall is 1310 mm (1971) and the lowest 113.0 mm in the year 1937, showing a wide range of variation.

The mean annual rainfall for Khair and Nojhil are 721.81 mm and 665.67 mm respectively. The average mean annual rainfall for the entire study area is 693.74 mm. The standard deviation at Khair is 232.57 and at Nojhil it is 288.54.

The co-efficient of variation in the sub-basin varies from 32.22 to 43.34%, minimum at Khair and maximum at Nojhil (Mat). This suggests that occurrence of rainfall varies mildly all over the sub-basin. The average coefficient of variation in the study area is 37.78% which

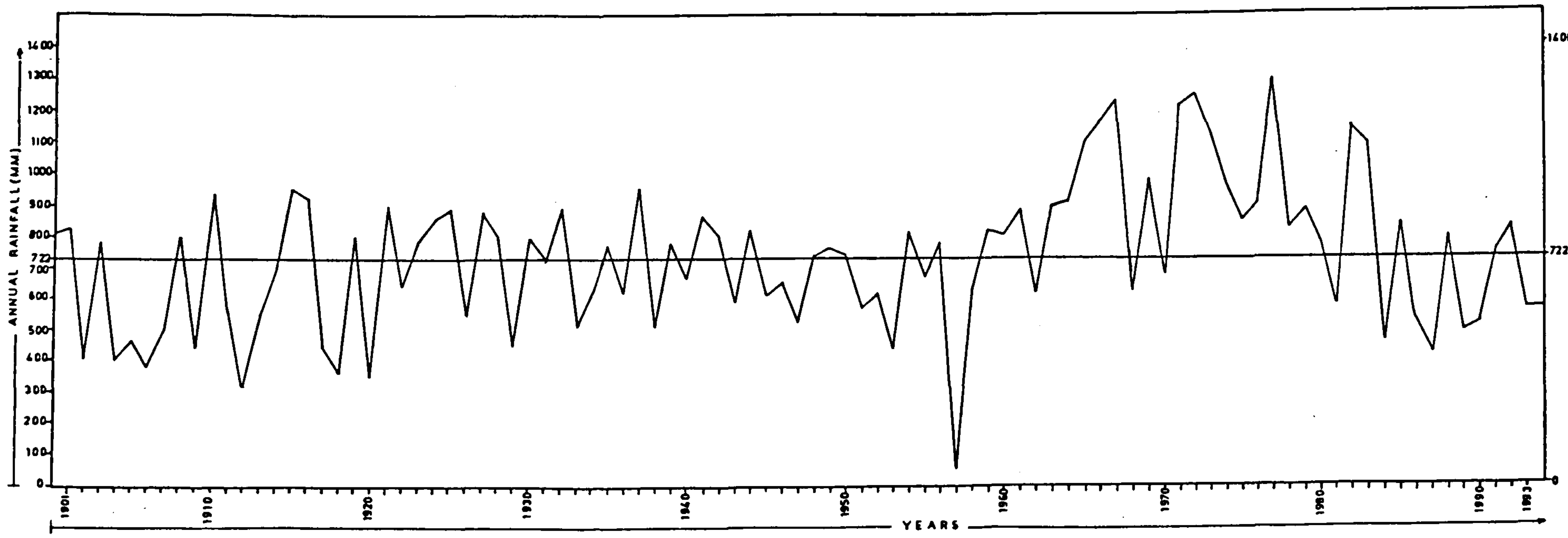


Fig. 2.3a: Departure of annual rainfall from mean rainfall at Khair.

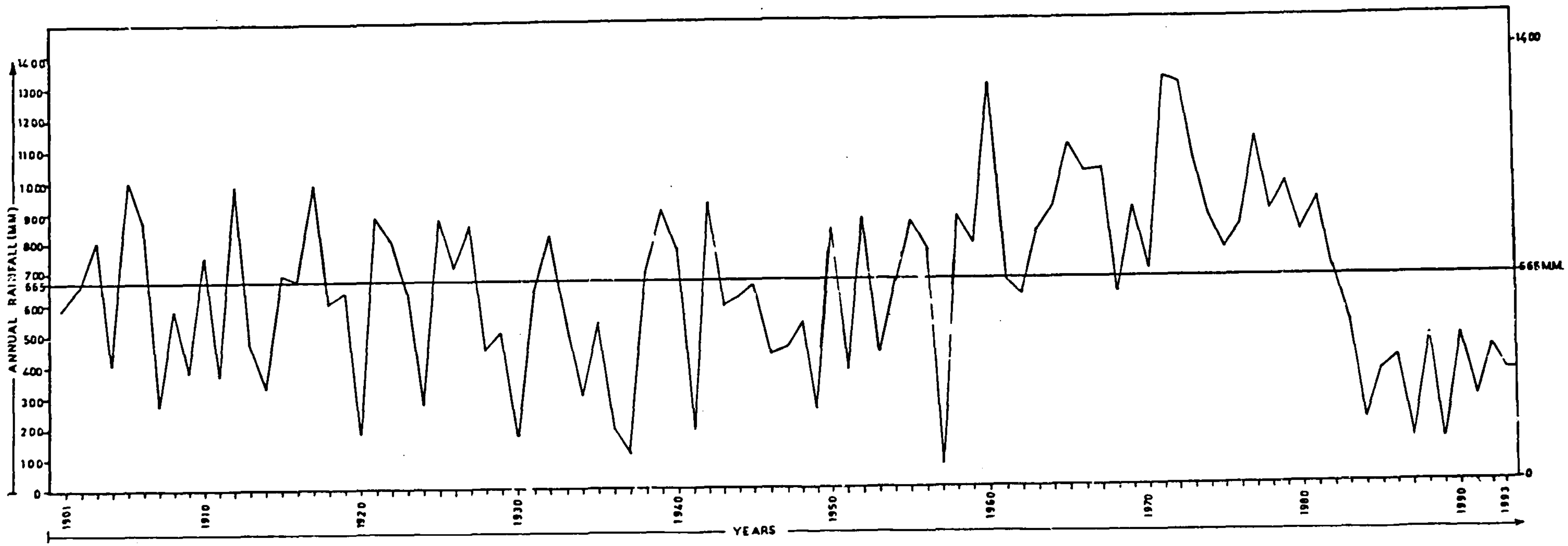


Fig. 2.3b: Departure of annual rainfall from mean rainfall at Nojhil.

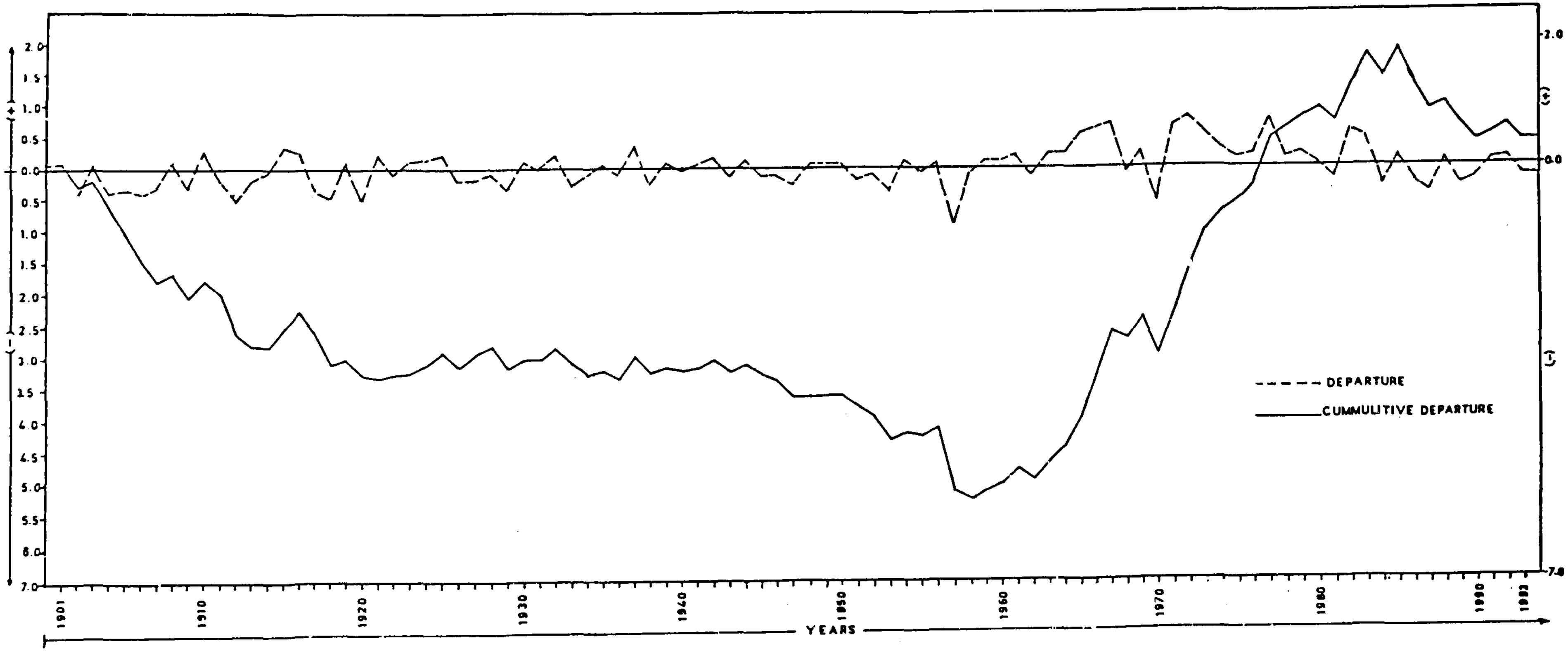


Fig. 2.4a: Departure and cumulative departure at Khair.

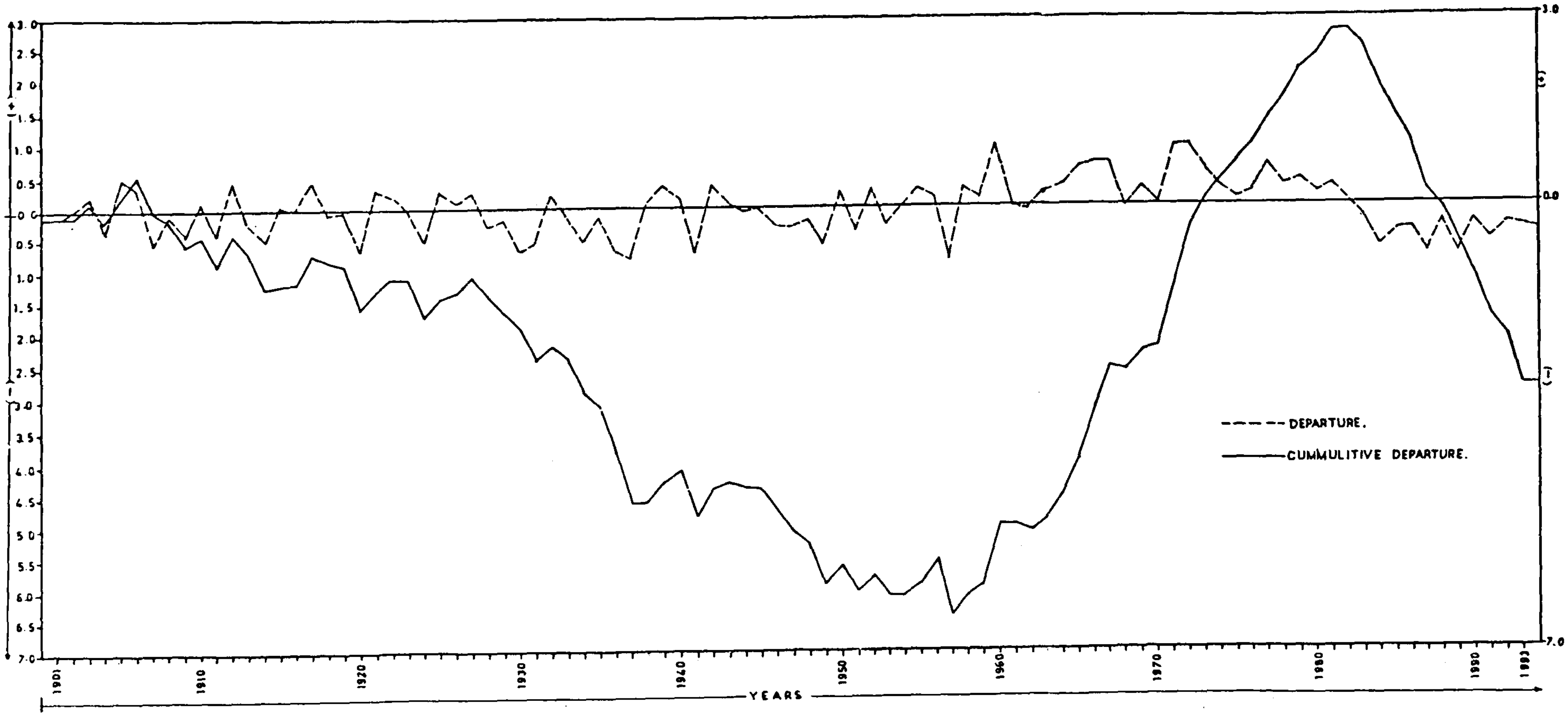


Fig. 2.4b: Departure and cumulative departure at Nojhil.

is considerably high and indicates a significant variability of rainfall in time and space.

Table 2.1: Results of statistical analysis of annual rainfall at Khair and Nojhil (Mat) raingauge stations.

Khair	
Highest rainfall (1972)	1242.00 mm.
Lowest rainfall (1918)	361.00 mm.
Mean (93 years)	721.81 mm.
Standard deviation	232.57
Coefficient of variation	32.22 %
Nojhil (Mat)	
Highest rainfall (19710	1310.00 mm.
Lowest rainfall (1937)	113.00 mm.
Mean (93 years)	665.67
Standard deviation	288.54
Coefficient of variation	43.34 %

2.6 DROUGHT ANALYSIS:

Rainfall varies in space and time. Droughts and floods are the consequences of this variability.

Drought is generally viewed as a sustained and regionally extensive occurrence of below normal natural water availability. Drought not only leads to serious economic consequences but it also leaves behind untold human misery. The variability of hydrological, hydrometeorological and agroclimatological conditions over space and time help in creating drought in the country.

The occurrence of drought leads to reduction in streamflow, and consequent reduction in reservoir and tank levels, depletion of soil moisture and groundwater. This on a continued basis leads to reduced availability of fodder, decline in agricultural production and domestic water supply. The drought characteristics and associated problems vary from area to area. Upon the amount of variability of available water supplied and the demand of water for specified users. But with the developing techniques of operational management of our water resources, a drought condition has to be viewed from 3 different aspects (Upadhya et al. 1989).

a) ***Metereological:***

When the actual rainfall is less than the normal (long term climatological mean) by 25% more over an area.

b) ***Hydrological:***

When there is marked depletion of surface water sources.

c) ***Agricultural:***

When soil moisture is inadequate to support healthy growth of crops. Water table goes deeper and ground water is unable to meet the demand.

As the study area is mainly an agricultural tract and forms a part of central Ganga plain, hence the computations are mainly based on agricultural definition of drought which takes into account the negative departure of rainfall from the mean. The classification of drought based on the percentage of the negative departure of rainfall from its mean is as follows:

Percentage of Departure	Type of Drought
0.1 - 25.0	Mild drought
25.1 - 50.0	Normal drought
50.1 - 75.0	Severe drought
75.1 -100.0	Most severe/rare drought

Table 2.2 and 2.3 show the year and frequency of occurrence of droughts in the study area. The analysis of tables shows that the area in general has been experiencing droughts of varying intensity over the period (1901-1993). Study shows that the average frequency of mild drought is 19.66%, normal drought is 18.47 while the average frequency of severe drought is only 8.16% and very severe drought is recorded at Nojhil i.e. 4.26%.

Table 2.2: Result of Drought Analysis at Khair

Types of Drought	Years	Frequency of occurrence
Mild drought (0-25%)	1911, 1913, 1914, 1922, 1926, 1931, 1934, 1936, 1940, 1943, 1945, 1946, 1951, 1952, 1955, 1958, 1962, 1968, 1981, 1993	20.65%

Normal drought (25-50%)	1902, 1904, 1905, 1906, 1907, 1909, 1917, 1918, 1929, 1933, 1938, 1947, 1953, 1957, 1984, 1986, 1987, 1989, 1990	20.65%
Severe drought (50-75%)	1912, 1920, 1970	3.26%

Table 2.3: Result of Drought Analysis at Nojhil

Types of Drought	Years	Frequency of occurrence
Mild drought (0-25%)	1901, 1902, 1908, 1918, 1918, 1923, 1929, 1933, 1935, 1944, 1945, 1948, 1954, 1961, 1962, 1968, 1983	18.47%
Normal drought (25-50%)	1904, 1909, 1911, 1913, 1914, 1928, 1946, 1947, 1951, 1953, 1985, 1986, 1988, 1990, 1992, 1993	16.30%
Severe drought (50-75%)	1907, 1020, 1924, 1930, 1931, 1934, 1936, 1941, 1949, 1957, 1984, 1991	13.04%
Very severe drought (75-1003)	1937, 1987, 1989	3.26%

2.7 SOIL TYPES OF THE AREA:

The soils of study area are much the same in composition and appearance as those of the doab. It is observed that the topography has great influence on the soils of the area. The alluvium brought by the Yamuna river spreads almost all over the area. The alluvial soils of the study area has been divided into two broad geological divisions - the older alluvium and the newer alluvium. The older alluvium is in the process of denudation while the newer alluvium is in the process of building up (I.C.A.R., 1969). The Bhangar soils occupies the level plains above the general flood limits of the main river. These soils vary from clayey loam to sandy loam depending on the land form and the drainage of the region. The soil at places, is characterised by the presence of impure calcareous concretions or 'Kankar' and are found at various depths. The soils differ greatly in texture and consistency ranging from the sands through loams and silts to heavy clays that are ill drained and are sometimes charged with injurious accumulations of sodium salts producing a sterile deflocculated conditions called 'Usar'. The 'Khadar' lands are found in narrow strips along small rivers whereas along the river Yamuna, the area is considerably wider.

The soils of the study area have been classified into the following three types (Fig. 2.5) on the basis of profile, texture, colour etc. (Annon, 1992).

1. Sandy loam
2. Clay to clayey loam
3. Loam to sandy loam

1. Sandy loam:

This soil region covers the largest area and occupies the upland tract. This tract runs from Karwan

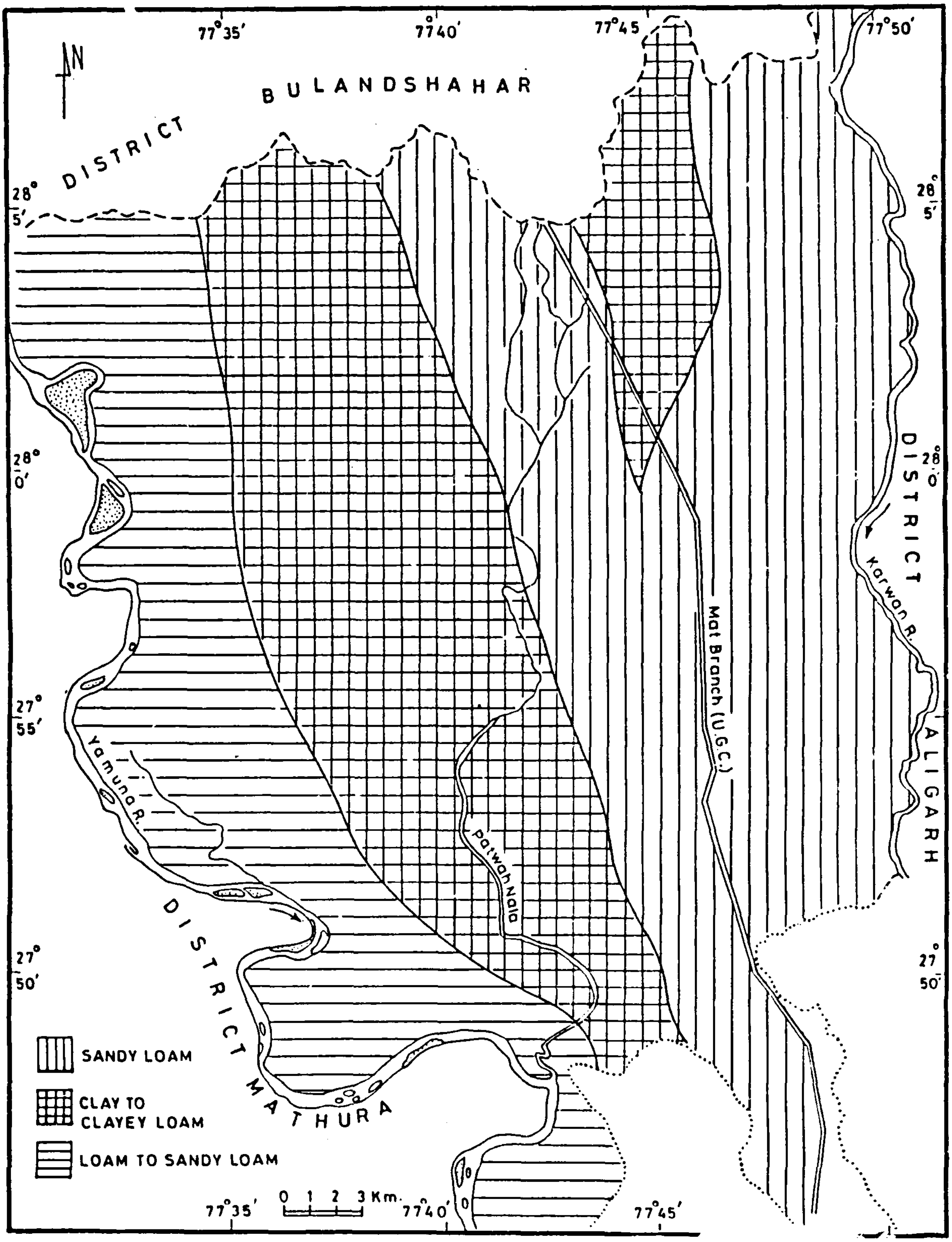


Fig. 2.5: Soil map of the study area.

river in the east to the Patwah nala in the west. The Karwan valley of this region has a very narrow strip of soil. This area is drained by an artificial drainage system known as Ganda nala (dirty drain). Many other natural and artificial drainage lines are found there. Therefore, the area is not affected by water logging and swampy conditions and due to this there is absence of large stretches of usar soils.

The soils are sandy in texture and brown or raddish brown in colour. The area contains a number of sandy ridges. The soil of these sandy ridges are locally called as 'Bhur'. The water holding capacity of these soils is low. They are suffering from the deficiencies of organic matter and other plant nutrients. They are also deficient in calcium and clay due to excessive leaching. The lower horizons are also course textured. The water table is deep. Iron mottling may be seen in soil profile. Since the process of evaporation exceeds precipitation, the soil contain considerable quantities of soluble salts. For this reason, the soils are not acidic in reaction and the pH value of these soils varies from 7-8 (Agarwal,et al. 1952).

Clay to clayey Loam :

This tract occurs in north-western part of the area with a varying width from 9.65 km in the north to about 3.2 km. in the South. At the time of flood in the Yamuna, these soils are over flooded. They are clay to clayey loam in texture and dark grey to black in colour. These soils are poorer in sand fractions and are rich in clay and silt which accounts for 60 to 75 percent of the soil. The tract is underlain by thick pan of calc concretion called 'Kankar'. The soil are strongly alkaline in charactaer and the pH usually ranges from to 7-9.

Alkalinity and the bad physical character of the soils render them difficult for normal agricultural use. The bad physical nature is due to the high sodium saturation in the echange complex of its sub-soils. The percentage of clay decreases with the increase in depth which shows an ideal example of water logged soils where the impermeable sub-soil horizon does not allow the translocation of even the finest clay particles. Due to poor drainage, the soluble sodium salts are deposited on the surface in the form of salt afflorescence.

Loam to Sandy Loam:

This tract is about 9 km wide and lies almost parallel to the Yamuna Khadar tract in the form of a narrow belt in the eastern part of Yamuna. Topographically, this is a flat region made up of stiff loamy soils which becomes lighter in the south ultimately converging into the ridges of 'bhur'. The texture of these soils varies from good quality loam to sandy loam. The clay percentage in the sub-soils is higher than at the surface. But the bottom layers are highly sandy having a sand proportion of about 78 percent. The colour of the surface soil is ash grey while the sub-soil are darker. These soils are compact, having restricted drainage and all the layers of the soil contain 'Kankar' nodules. They are neutral to slightly acidic (pH 7-6.2) in the surface layers and slightly alkaline towards the bottom. Water retaining capacity of these soils is poor. Generally, the surface soil to a depth of 30-35 cm is well drained soil and contains loose loam that can easily be ploughed and cultivated.

2.8 LAND USE PATTERN IN YAMUNA-KARWAN SUB-BASIN:

The study area includes the Khair and Tappal blocks of Khair Tehsil, district Aligarh and Nojhil block of Mat Tehsil of district Mathura, constitutes over all geographical area of about 1033.01 sq. kms. (103301.33 hectares) based on the statistical information for the year 1991-92. The entire sub-basin consists of about 88% of cultivated land in which the different types of crops are sown. With existing facilities for irrigation, nearly 83.33% of the cropped area is irrigated from different sources. Only about 16.6% of the cropped area remained unirrigated.

Land utilisation patterns of the area are furnished in the following table.

Table 2.4: Showing distribution of the area (1991-92)

Items	(hectares)
Total geographical area	1,03,301.33
Gross area under cultivation	1,02,64[illegible].00
Net area sown	86,380.33
Forest	300.00
Permanent pastures and grazing land	551.00
Current Fallows	3,061.00
Other fallows	1,841.00
Area sown more than once	37,303.00
Cultivable waste land	2,273.00
Barren uncultivable land	3,[illegible]6.00
Land under miscellaneous trees crops and goorves	5,156.00

2.9 IRRIGATION:

Irrigation in the area is being provided both by surface water and groundwater. The high standard of agriculture in the sub-basin is in large measure due to the exceptional facilities which it enjoys in the matter of irrigation. Inspite of the great extension of canal system (i.e. Mat branch of upper Ganga canal and its tributeries pass through the area), shallow and deep tubewells form the chief source of the irrigation water supply. Area irrigated by different sources is given as under:

Table 2.5: Showing area irrigated through different sources.

Sources	Net irrigated area (in hectares)
Canals	14,161.01
Tubewells (State & Private)	70,171.70
Dugwells	650.00
Tanks, Ponds & Lakes	200.00
Others	150.00
	[illegible],332.71

Perusal of the table 2.5 indicates that out of the total 85,332.71 hectares irrigated area, 82.99% is irrigated through groundwater structures while only 16.82% area is irrigated through canal net works and other sources.

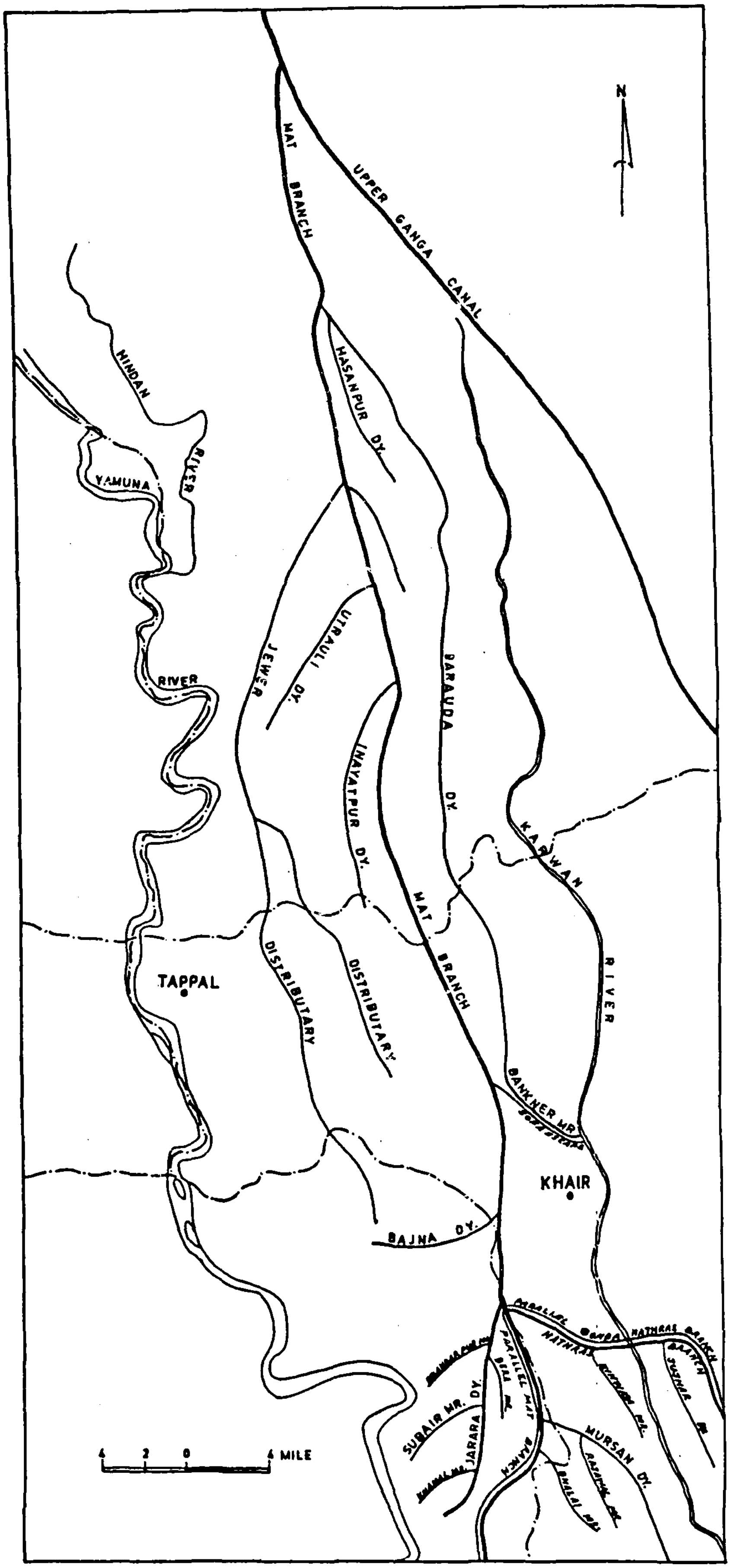


Fig- 2.6: Showing the Mat branch feeder canal and distributories (Source, U.P. Irrigation Department, Aligarh).

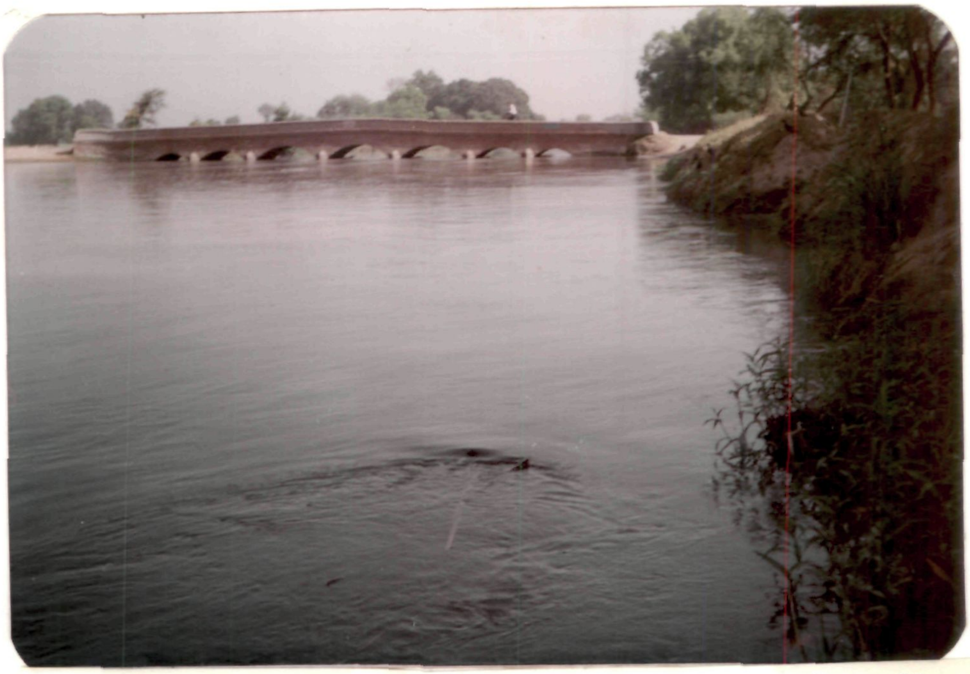
PLATE - XII A

A view of unlined feeder canal (Mat branch) traversing through the study area.

PLATE-XIII

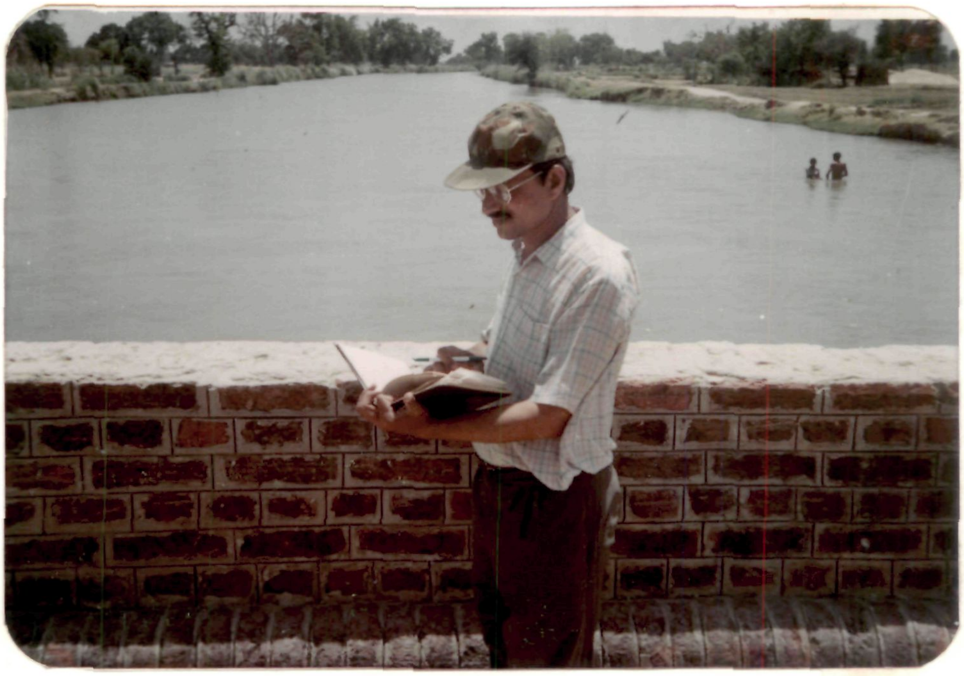
A view of Jhil (lake) near Manpur village.

PLATE-XII B



A view of Mat branch (Feeder Canal) with flow intensity.

PLATE-XII B



Quite flows Mat branch feeder canal'" down the bridge.

Mat Canal:

The study area has a main canal i.e. Mat branch of upper Ganga canal which is mainly aligned in a north to south direction, probably due to easy flow of water (Fig. 2.6 and Plate XII).

Mat branch project was introduced by Sir Proby cautloy to irrigate the area between the Karwan and Patwah rivers. Mat branch enters the study area through the central part of Khair and running from north to south, it touches the western boundary of Aligarh district and enters the Mathura district. The canal with a head discharge of about 56.60 cumec is supplemented by seven distributaries and 44 channels (Fig. 2.6). The central part of the Khair tehsil is irrigated by Mat canal and its various distributories like, Barauda, Shadipur, Jewar and Bajauta. The channels and minors of the Mat branch canal irrigate the driest portion of Tappal block along the high bank of river Yamuna.

2.10 WATER USE PATTERN:

Out of the total water resources of the Yamuna-Karwan subbasin, 16.06% is derived from the surface water source and 83.86% from the groundwater sources (Fig. 2.7 Plates XII, XIII, XIV). The Mat branch of upper Ganga canal, its distributaries and minors supply the surface water for irrigation mainly for Khair and Tappal blocks (Plate-XVI).

Administratively, the study area is divided into various integrated developmental blocks and accordingly the blockwise water use pattern is shown as under:

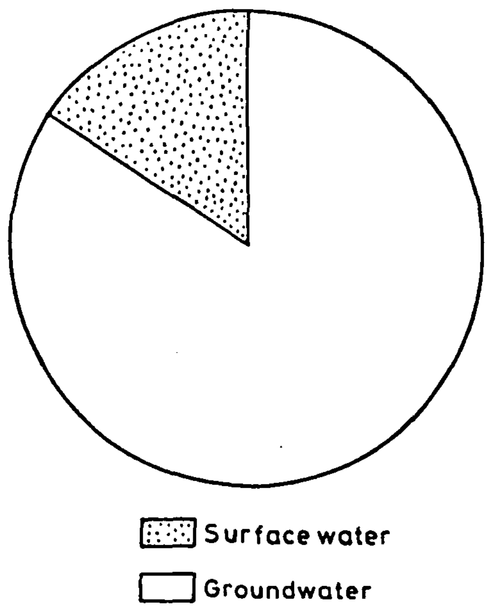


Fig. 2.7: Pie diagram showing water utilisation pattern in the study area.

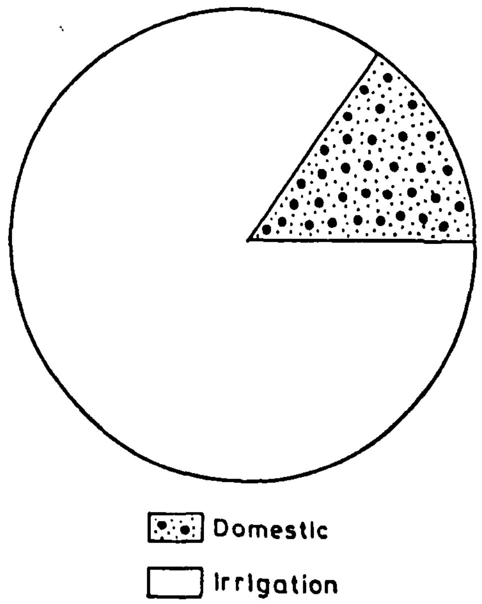


Fig. 2.8: Pie diagram showing groundwater use in the study area.

PLATE-XIV

Thirsty men and sheeps enjoying water coming out of a shallow farmer's tubewell near village Gharbara.

PLATE-XV

A view of a dug well at Khera village.

Table 2.6: Contribution of surface and groundwater for irrigation in different blocks in year 1992-93

Blocks	Percent area irrigated by surface water	Percent area irrigated by the groundwater
Khair	13.19%	86.81%
Tappal	14.4 %	86.6 %
Nojhil	22.9 %	77.0 %

Estimate of groundwater use of the sub-basin shows that out of the total groundwater withdrawn, 85% is used for irrigation purpose and remaining 15% is used for domestic purposes (Fig. 2.8) which also includes livestock consumption.

CHAPTER - III

GEOLOGY

GEOLOGY

3.1 GENERAL GEOLOGY:

India is divisible into three distinct physiographic units viz., the Peninsular shield, the Himalayas and the Indo-Gangetic plain (Fig. 3.1).

Peninsular shield is composed of geologically ancient rocks of diverse origin, most of which have undergone much crushing and metamorphism. Structurally, the Peninsula was supposed to represent a stable block of the earth crust which has remained unaffected by mountain building movement since the close of Precambrian era, however in recent months doubts have been expressed about its stability.

The Himalayas is a region of folded and over-thrust mountain chains of about 65 million years old. Their curvilinear structure is very striking. They consist mainly of circular arcs which are convex towards Peninsula i.e. towards the rigid crust against which they appear to have been thrust (Krishnan, 1968). Though, the Extra-Peninsula contains some very old rocks, it is predominantly a region in which sediments were laid down in a contineously deepening depression between two plates from the Cambrian to early Tertiary age. The rivers of the Himalayas are youthful and are actively eroding their beds in precipitous courses and carving out deep and steep sided gorges and flow across it in order to join the plain.

The Indo-gangetic plains in which the study area lies, are broad, monotonous, level expanses built up of

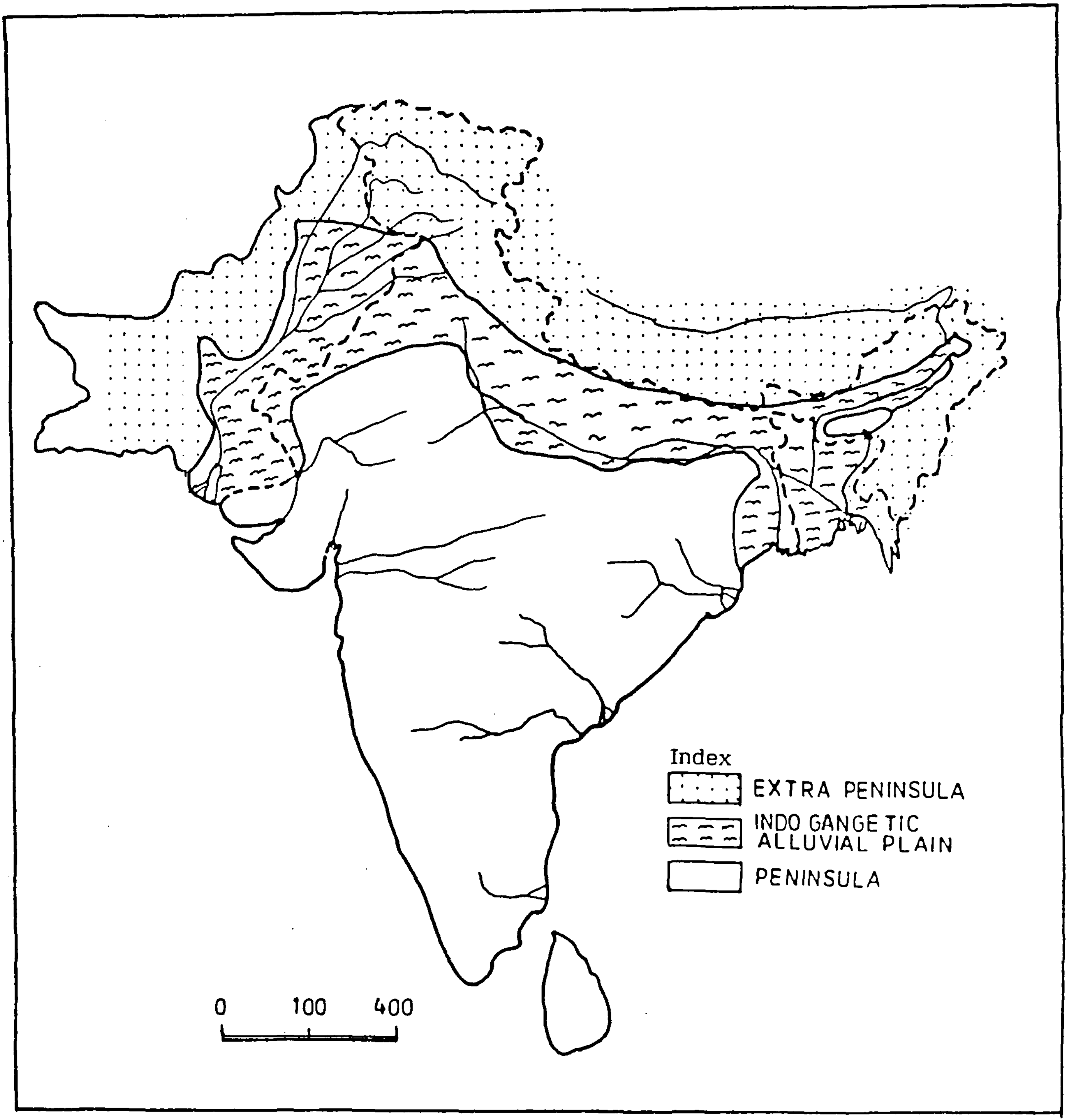


Fig. 3.1: Physiographic divisions of India.

Quaternary alluvium was brought down by the rivers draining the Himalayas and which forms the major unit in the geology of the Indian subcontinent. It includes the great alluvial tract of the Ganges, Brahamputra and Indus covering an area of 85000 sq. kms. (Krishnan, 1968). The rivers of the Indogangetic plain flow sluggishly towards the Bay of Bengal or Arabian Sea.

Earlier, there has been much speculation regarding the sub-surface geology and tectonic origin of the vast depression of Gangetic alluvial plain. The plain line deflection and gravity data obtained by Survey of India, many years ago, were too meagre to give any concrete indications of the sub-surface geology. The tubewells drilled for groundwater did not go down beyond a depth of 600 metres and the data on solid goelogy of the plains was lacking entirely. However, with the advent of geophysical exploration in these plains about three decades ago, a farily large volume of data indicating the nature of sub-surface geology and structure has been obtained which was further substantiated by number of deep exploratory wells drilled in these plain by Oil and Natural Gas Commission.

Although, the Indo-Gangetic plain appears as one vast stretch from one end to other, geologists have held the opinion for a long time, that the floor of this plain is not an even but there are hidden ridges and depression which lies under the alluvium (Rao, 1973). Ridges refer to the linear aeromagnetic anomalies, which are structural features of the Ganga plains, might have formed important topographic divides at the time of Vindhyan deposition, but subsequently peneplained, and the overlying Siwaliks occur with nearly uniform thickness across the ridges.

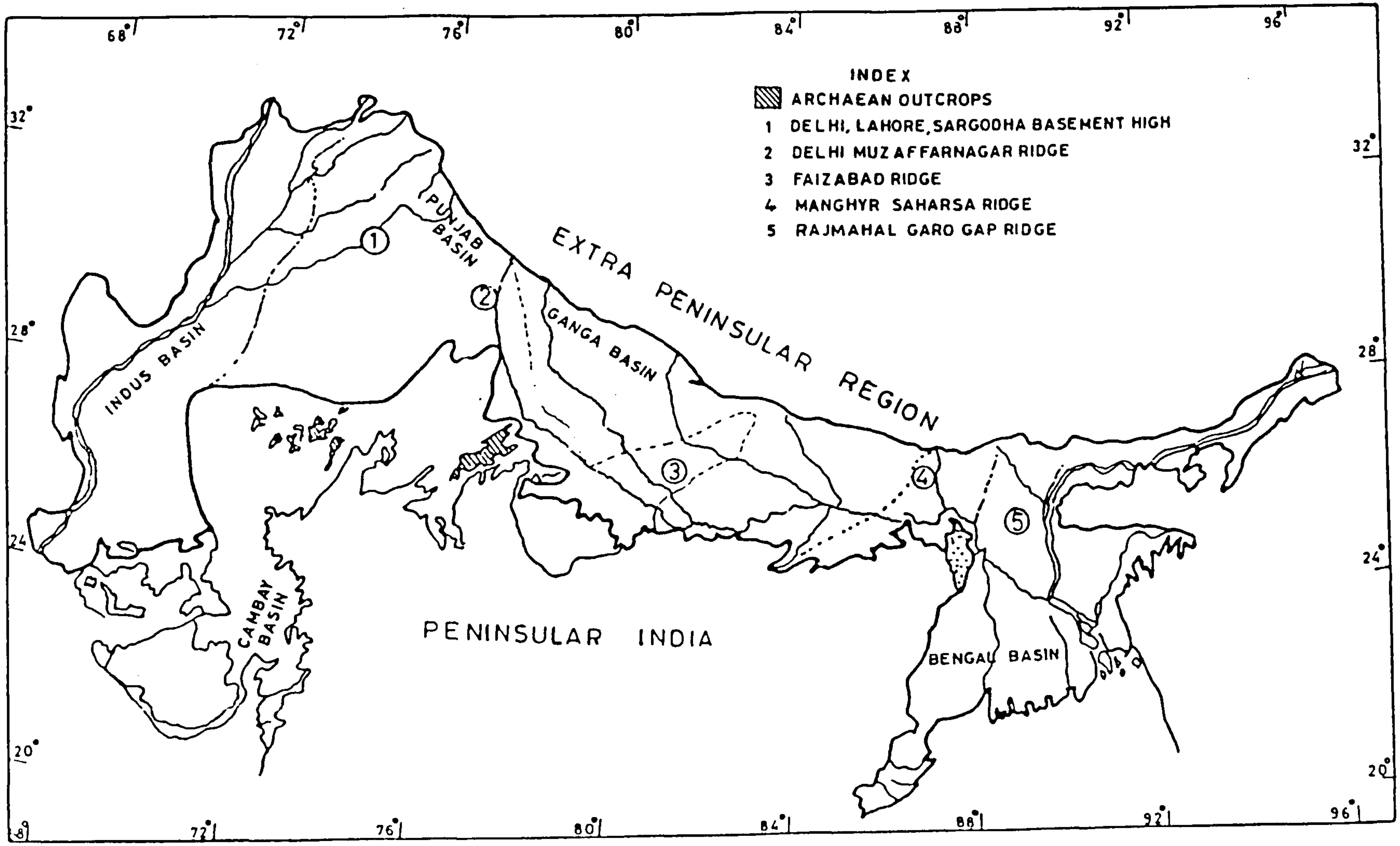


Fig. 3.2: Map of Indo-Gangetic plains indicating the main divisions.

Geologists believe that below the alluvial covering, there is an appreciable diversity in the constituents of rock formation. Estimate of thickness of the Ganga alluvium have been ranged from about 15 kms (Burrad, 1951) to 4.5 kms (Oldham, 1917). Further, Wadia (1966) and Krishnan (1968, 1982) have been pointed out that beneath the alluvium, the sedimentary formation of palaeozoic, mesozoic and tertiary ages may be found, which is supported by reported occurrance of upper proterozic Vindhyan in Ujhani and Aligarh. At Kanpur and Ujhani, however, Bundelkhand granite was on countered at a depth of 504 m and 2161 m b.g.l. respectively.

The most important basic data regarding the basement configuration and sedimentary basin of the Indo-Gangetic plains are provided by Agcos (1957). Basement depth contours for the whole of Indo-Gangetic plain have also been counted by aeromagnetic data which shows increasing thickness of sediments along the foot hills of the Himalayas. The maximum depth to the basement as indicated in Seismic surveys is about 6 kms along the northern boundary.

The Indo-Gangetic plain can broadly be divided into the following five basins (Fig. 3.2) from west to east these are:

1. Indus basin of Pakistan
2. The Punjab basin in the Punjab
3. Brahamputra basin in Assam
4. Bengal basin in West Bengal and Bangladesh
5. Ganga basin in U.P. and Bihar

The Indus Basin:

Except for the area under Thar desert in Rajasthan, a greater part of the Indus basin lies in Pakistan. It is filled up by sediments which started in early Paleozoic to quarternary and possibly also by Vindhyans remnants which are found in westernRajasthan (Krishnan, 1968). This basin is 6000 m deep in Sind. A large thickness of Tertiary and Mesozoic sediments have been met under the alluvium. This thick marine sequence has thinned out towards Rajasthan platform.

The Punjab Plain:

The Archean basement rocks occurring under moderate thickness of alluvium in Lahore-Sargodha area seperate the Indus basin in the west from the Punjab depression in the east. The Seismic Survey by the O.N.G.C. (Datta et al., 1964) has indicated that the basement surface as well as sediments below the alluvium gently dip towards the foothills due west. However, the basement becomes deep as foothills are reached with corresponding increase in the thickness of sediments. The maximum depth of basement is 4.5 kms. (Datta et al., 1964).

The Brahmaputra Basin of Assam:

The Brahamaputra basin lies between the Himalayan foothills and Shillong-Mikir hills. In this basin the sediments attain appreciable thickness as the basement becomes deeper and deeper close to the Himalayan foothills. However, the basement is shallowest towards the Mikir hills.

The Ganga Basin:

The Ganga basin, occupying an area of about 250,000 sq.km. falls within Long. 77° E and 88° E and Lat. 24° N

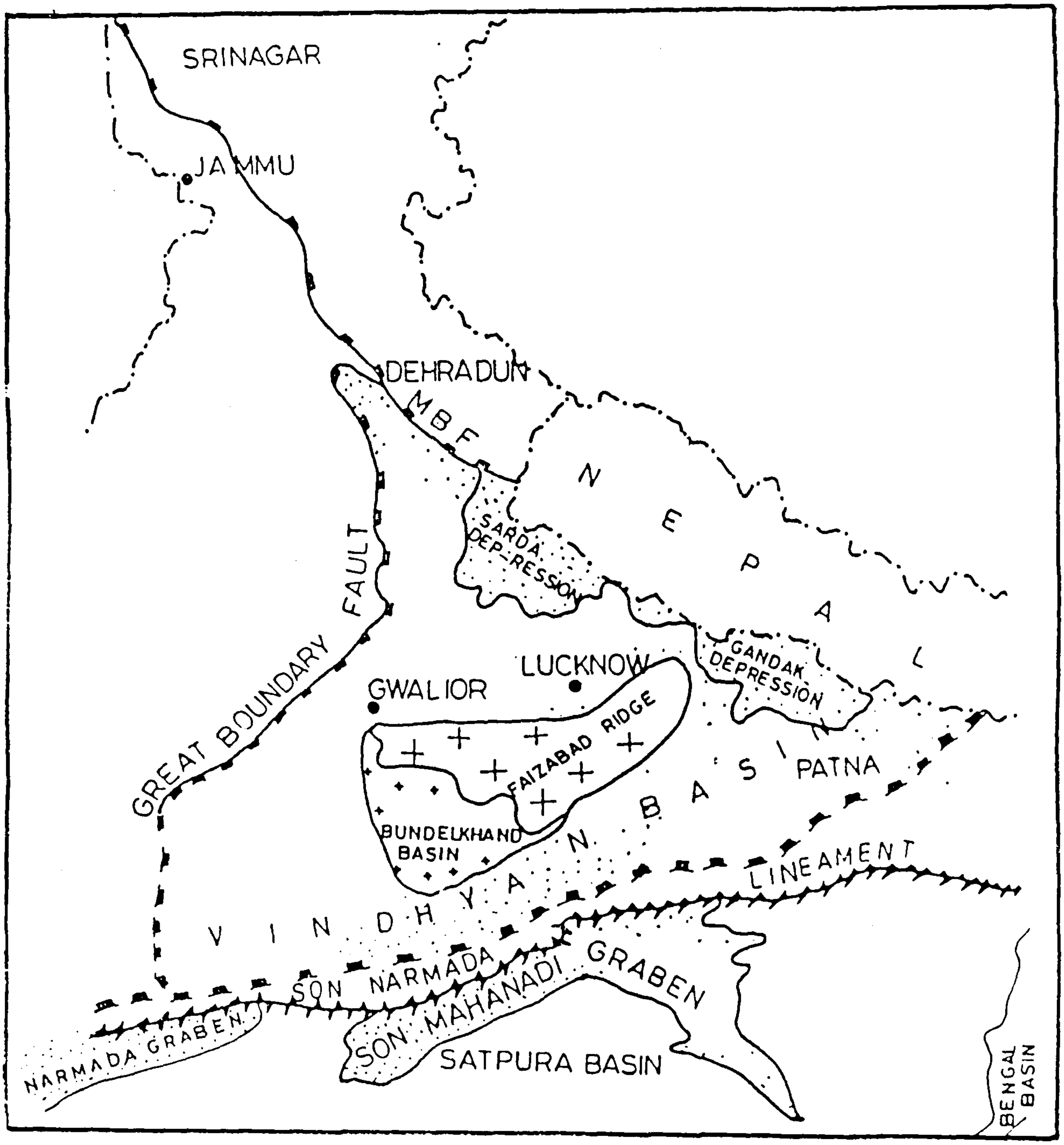


Fig. 3.3: Showing the major tectonic features of the Ganga basin.

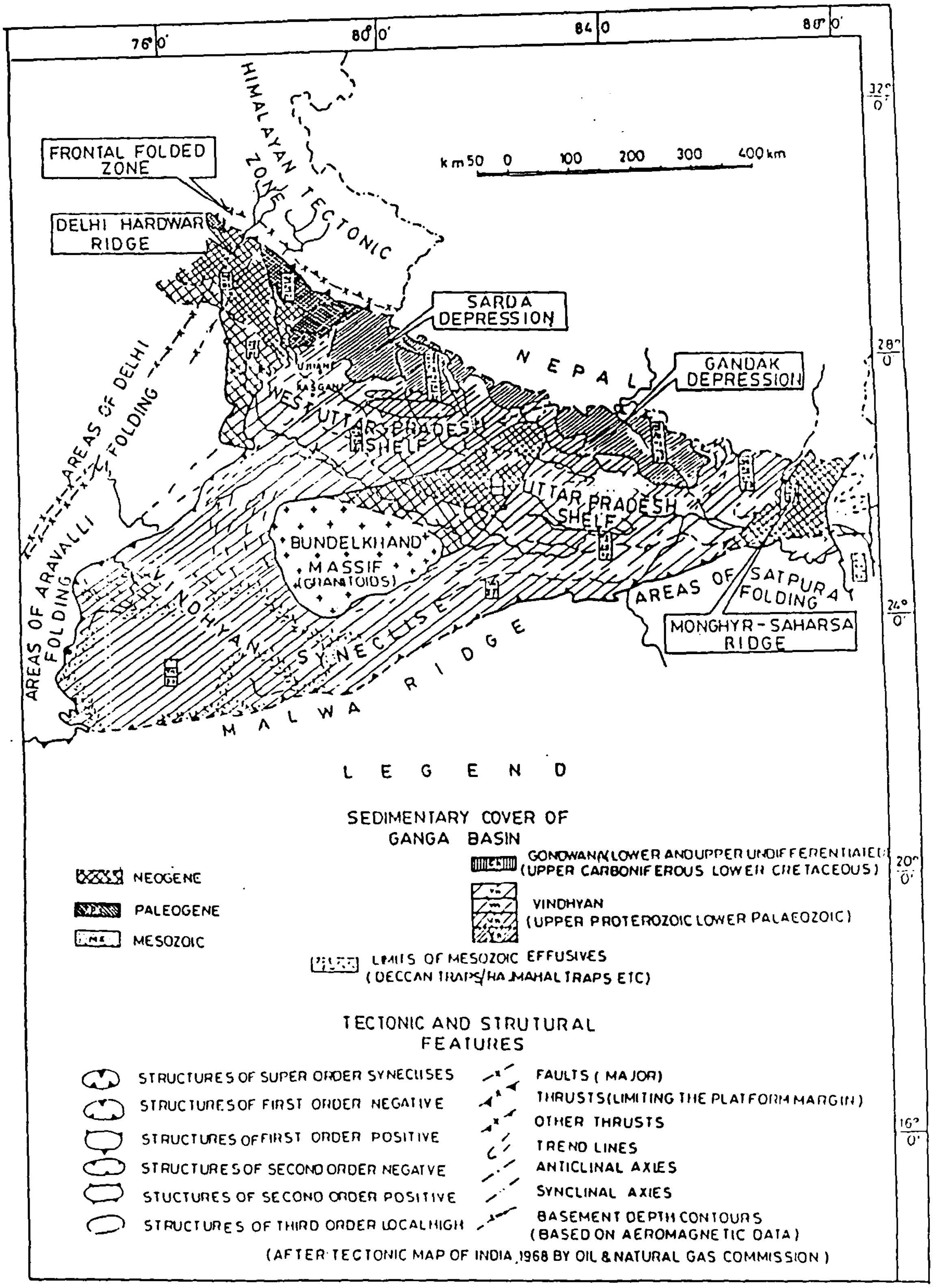


Fig. 3.4: Tectonic map of Ganga basin and adjoining areas.

and 30°N. It includes more than half of the total area of Indo-Gangetic plain. This basin comprises a great long sedimentary area, flat and monotonous which is drained by the river Ganga, and its various tributaries. The western margin of the basin is bounded by Delhi-Hardwar ridge with middle Proterozoic rocks and in the east by the Archean Monghyr-Saharsa ridge. To the north, the Ganga basin is limited by outer most Siwalik foothills of the Himalayas bounded by the Himalayan Frontal fault which runs parallel to the Himalayas from west to east. Along the southern fringe of the basin, Bundelkhand granite-gneiss, Delhi Super Group and the Upper Vindhyan Group of rocks are exposed. The Ganga basin represents a large scale regional depression on the northern margin of the Indian platforms and is considered as super order crustal structure of negative character most probably forming a northerly continuation of Vindhyan Syncline (Shastri, 1971) (Fig. 3.3 & 3.4).

3.2 ORIGIN OF THE GANGA BASIN AND STRATIGRAPHY OF THE STUDY AREA:

There has been more speculation regarding the sub-surface geology and tectonic origin of the vast depression of the Gangetic alluvial plain which came into existance in the Pleistocene period. This land lying in front of the newly risen Himalayas, formed a depression, which was rapidly being filled up by sediments coming from the rising Himalayas and the Peninsula. Various hypothesis have been put forward to explain the geological evolution of this plain. Suess (1904-1924) has suggested that it is a 'fore-deep' formed in front of the high crust waves of the Himalayas as they were checked in their southward advance by the inflexible solid land mass of the Peninsula. On the basis of physical and geodetic considerations Burrad (1915) considered that the Indo-Gangetic Plain occupies 'rift-valley', a portion of the earth's surface sunk in a huge crack in the sub-crust, between parallel faults on its two sides. This rift extends from the surface for down into the crust about 32 kms. deep and is subsequently filled up by alluvium. This view has got few geological facts in its support but is not adopted by geologists, who believe that the Indo-Gangetic depression is a true 'fore-deep', a down-warp of the Himalayan foreland, of variable depth, converted into flat plains by the simple process of alluviation. In this view, a vigorous sedimentation took place and this deposition kept pace with subsidence giving rise to this tectonic trough of India (Valdiya, 1981).

According to Krishnan (1982) the Indo-Gangetic alluvial trough is a region whose origin and structure are closely connected with the formation of the Himalayas. He suggested that the Gangetic plains owe its origin to a sag or depression which has been formed by buckling down of the crust in obedience to pressure exerted on the borders of the Peninsula by compressive forces. Valdiya (1982) interpreted it as a resultant effect of sagging of the northern flank of platform around the Bundelkhand shield following the main episode of the Himalayan orogeny. The depression was filled up with sediments brought by rivers flowing from the Himalayas and the Peninsula (Sharma and Coutinho, 1980).

Dickenson (1974) has emphasized that the major sedimentary basins developed between fold-thrust belts and the craton, over which the mountain belt is thrust. Miall (1981) and Bally (1981) call these basins fore-land rather than fore-deeps. Fore-land basins are asymmetrical, and deepest near to the fold thrust belt they migrate towards the fore-land and have resulted from down-ward flexturing of the lithosphere by over-riding fold thrust bolt (Beaumount, 1981).

Dickenson (1974) considers the Indo-Gangetic trough as the most impressive, present day peripheral fore-land basin formed as the result of continent-continent collison between Indian and Asian plates. the basin has developed on the under thrust Indian plate and due to loading of thrust sheets in Himalayas causing a viscoelastic flexture in the crust allowing sediments to accumulate under fluvial process.

According to Singh (1989) the Gangetic plain is a part of active fore-land basin (peripheral type) developed on the under thrusting Indian plate, in response to the thrust fold belt loading in the Himalayas. Further, Singh and Ghosh (1988) and Singh (1989) opined that during thrust-fold loading tectonics in the Himalaya, the Son-Narmada lineament much to the south of the fore-land basin was reactivated, causing uplift of Bundelkhand-Vindhyan plateau and development of northerly slope (Fig. 3.5).

The rate of subsidence of the old, rigid and cold crust of Indian shield was also low and sediment input by rivers high, so that no marine transgression of Neogene-quarternary time could enter into this fore-land basin. The deep drilling data of the O.N.G.C. is contrary to this view of Singh, as the deposits of Neogene sediments are reported from all over the Ganga basin (Sastri, 1971, Rao, 1973).

The exact thickness of the alluvium has not been ascertained, but recent gravity, magnetic and seismic

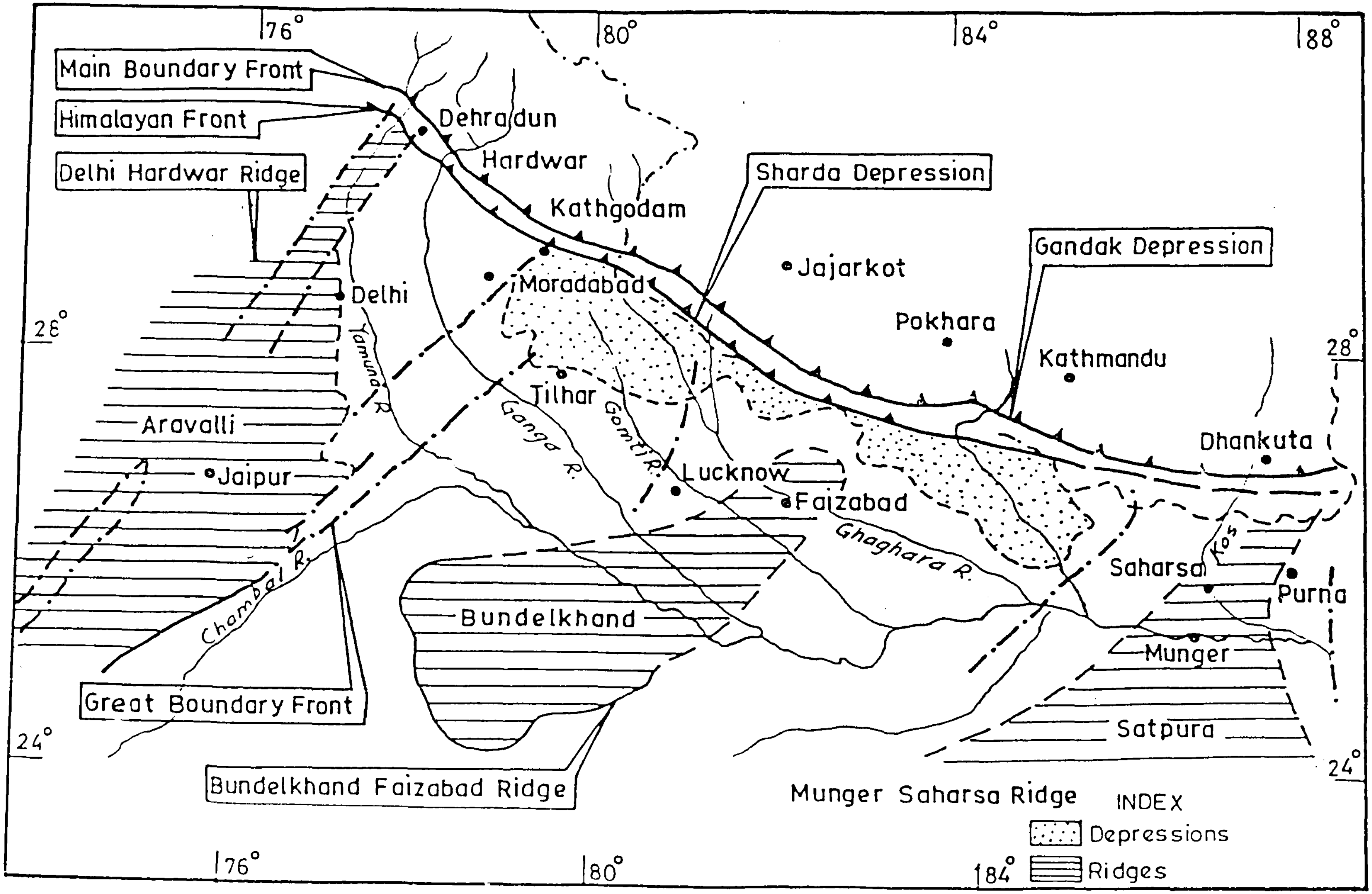


Fig. 3.5: Shows the structure of the Ganga basin.

explorations show that it is variable from less than 1000 to over 2000 meters. Geologists differ in their estimates about the thickness of the alluvial deposits. However, the drilling carried out by O.N.G.C., have yielded stratigraphic informations pertaining to the sub-surface geological framework which indicates the presence of upper Vindhyans below the Siwaliks are as follows:

Table 3.1: Vindhyan Formations in Ganga Basin

Wells	Depth interval (metres)	Thickness	Age
Kasganj strcutural	620 - 1250	630	Upper Vindhyan
Ujhani deep well	1010 - 2062	1052	Upper Vindhyan
Tilhar	1718 - 2225	507	Upper Vindhyan
Puranpur	3174 - 4235	1061	Upper Vindhyan

On the east of Yamuna river Aligarh and Mathura districts, the upper Vindhyans have been encountered at different places during the exploratory drilling operations carried out by the Central Groundwater Board during last two decades (Dubey, et al., 1992). The bed rock, the upper Bhander sandstone touched at a depth of 286.62 m below the ground surface at Salempur near the eastern boundary of the study area. Further, below the sandstone occurs the upper Bhander red shale which was encountered at Aligarh Rly. JN. in 1976 and at Chandpah near Hathras (1991) at 340 and 365 m.b.g.l., respectively (Fig. 3.6). This shows that the

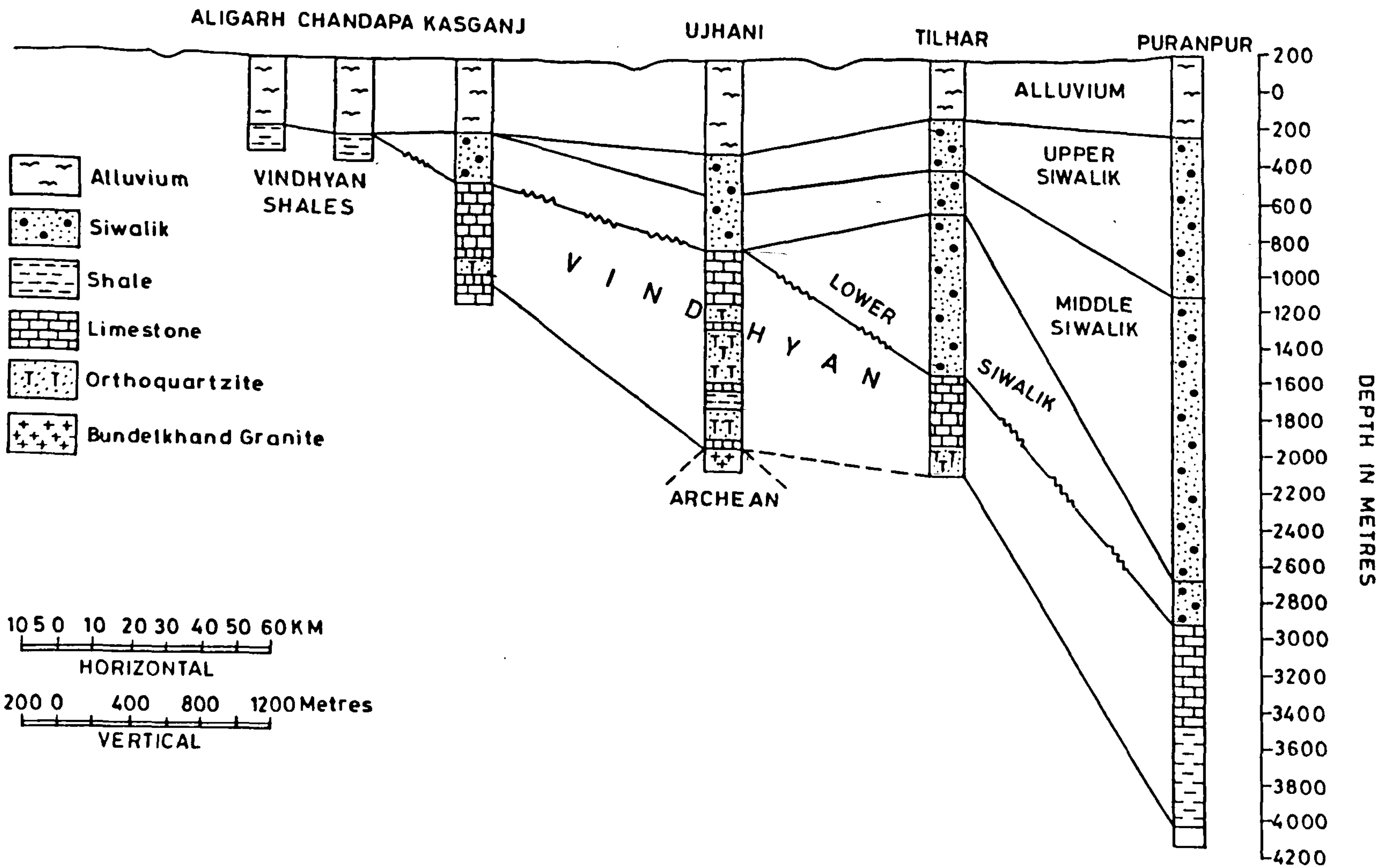


Fig. 3.6: Sub-surface geological cross section along Aligarh, Chandapa, Kasganj, Ujhani and Puranpur in parts of Central Ganga basin.

bedrock topography in the area is something like parallel to upper Bhander sandstone ridges, which maintains the topographic prominence and seperated by broad valleys. The shales are exposed in the valley and sandstone on the neighbouring ridges.

In the light of the above, finally the stratigraphic sequence in the study area is as follows.

Quarternary Alluvium	Alternate beds of sand and clay with occasional interbeds of calc-concretions (kankar)
------------------Unconformity------------------	
Upper Siwaliks Middle Siwaliks (Neogenes)	Coarse to medium sandstone with variegated clay stone and occasional carbonaceous streaks.
------------------Unconformity------------------	
Upper Vindhyan (Upper Proterozoic)	Upper Bhander sandstons Red shale Reddish brown argillaceous Limestone Greenish-grey dolomitic Limestone
------------------Unconformity------------------	
(Upper Archean)	Bundelkhand granite (Basement)

The Bundelkhand granite which is a big batholithic mass extends across the Ganga basin which further extends towards the Himalayan foothills. It underwent structural dislocation wherein the deposition of upper Vindhyan group of rocks took place. Thereafter, it underwent erosion and peneplanation for about 500 million years, and then the deposition of the Siwaliks took place. However, in the study area Siwaliks rocks were not encountered anywhere in Aligarh district. With the formation of the Ganga depression, it became the site of deposition, where huge sediments were contributed by the newly risen Himalayas and the rivers emerging from the northern fringe of the Peninsula leading to the healing up of the depression and giving thereby the present configuration of the Ganga basin.

CHAPTER - IV
HYDROGEOLOGY

HYDROGEOLOGY

Groundwater occurs in large reservoirs, beneath the watertable. it saturates the earth material through which it is moving and in which it is stored. Groundwater in its natural state is invariably moving and movement of the groundwater is from greater to areas of lesser hydrostatic head. The prime moving force is the hydraulic gradient. Occurrence, movement and storage of the groundwater is influenced by the sequence, lithology, thickness and the structure of the rock, formation. Movement and storage capacity is cheifly controlled by the permeability and porosity of the host rocks.

Lot of developments have been taken place and scientific procedures are available for evaluation, analysis and management of groundwater resources. However, R & D programmes have to be encouraged so that the evaluation of groundwater can be carried out on a more scientific ways to fill in the gaps and appropriately developed strategies evolved for alluvial regions and adequate attention has to be given on various aspects of groundwater resource, evaluation, planning and development.

The growth in population every year will need more quantity of food and fibre by the year 2000 A.D. this demands a refined re-evaluation of our groundwater resources afresh. Taking into account the above view; detailed hydrogeological investigations have been carried out in Yamuna-Karwan sub-basin in parts of Aligarh-Mathura districts, for the delineation of the regional aquifer systems and their groundwater resource potential.

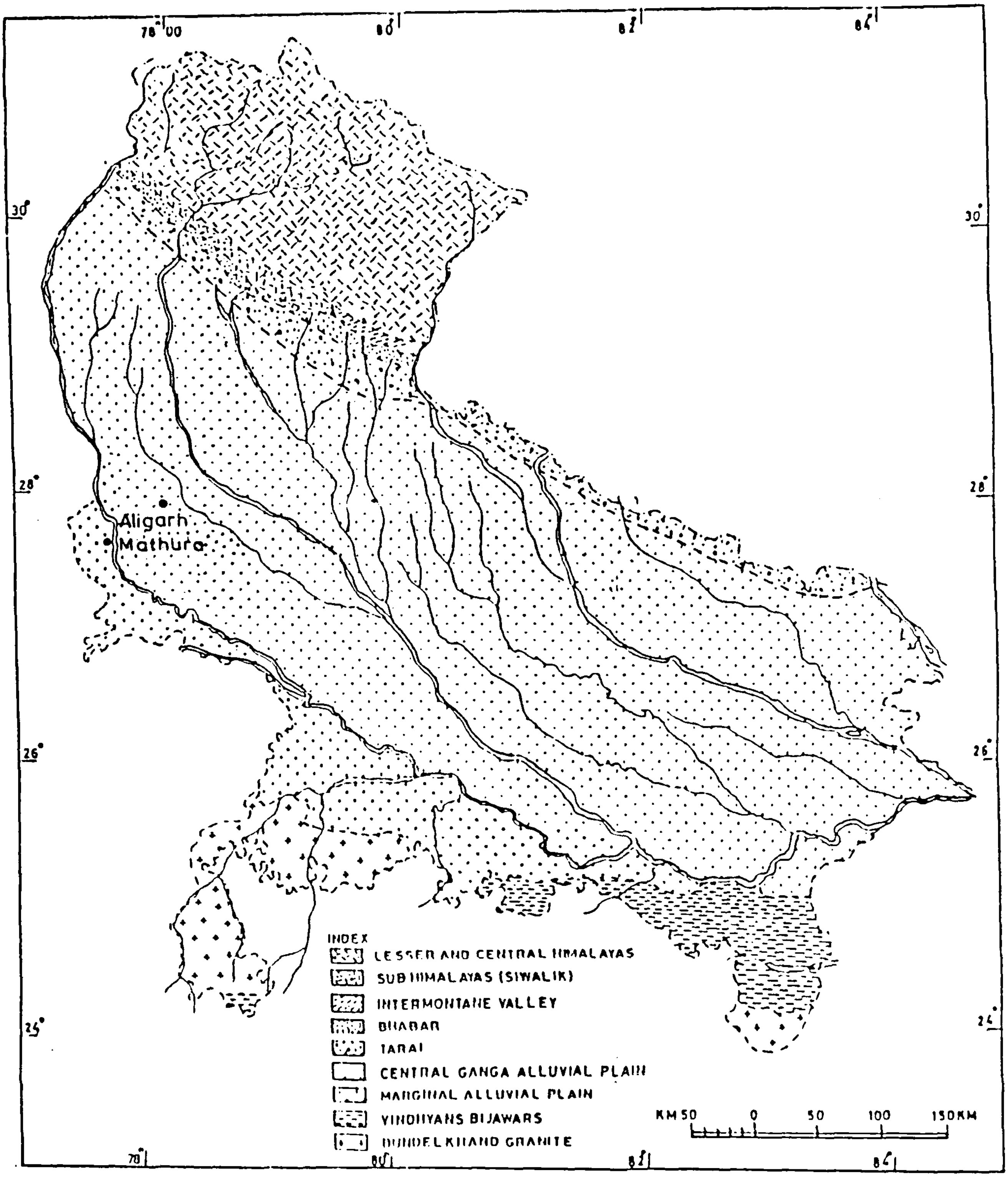


Fig. 4.1: Showing the Hydrogeological divisions of Uttar Pradesh (After Pathak, 1978).

4.1 HYDROGEOLOGICAL SETTING:

The Ganga basin forms one of the most potential groundwater provinces of India (Pathak, 1978) of which the state of Uttar Pradesh forms an important part. Out of a total area of 234,413 sq. kms. of the state, an area of 2,00,492 sq.kms. has been covered by systematic hydrogeological surveys. the greater part of the state is covered unconsolidated formations having extensive and productive aquifers with yield prospects of more than 15 m^3/hour. Extensive aquifers having yield prospects of less than 150 m^3/hour are located in Western Ganga-Yamuna 'Doab' covering the districts of Aligarh, Bulandshahar and parts of Agra, Etah, Mainpuri, Mathura, Meerut, Muzaffarnagar and Saharanpur districts; in the central part of the state covering parts of Barabanki, Faizabad, Lucknow, Rai Bareli, Sultanpur and Unnao districts and in eastern part covering the district of Ballia and parts of Azamgarh and Ghazipur districts. Local and discontinuous aquifers capable of yielding more than 150 m^3/hour are encountered in intermontane Doon valley. Southern marginal areas covering most of the trans-Yamuna plains and the area covered by semiconsolidated formations in northern Uttar Pradesh have local and discontinuous aquifers having yield prospects of less than 150 m^3/hour. In southern Uttar Pradesh fissured sedimentary and metasedimentary formations form aquifers capable of yielding more than 20 m^3/hour while the crystallines have local and discontinuous aquifers having yield prospects of less than 20 m^2/hour.

Based on physiography and hydrogeological conditions evaluated on the basis of systematic surveys and groundwater exploration the state can be divided into the following hydrogeological zones (Fig. 4.1).

Table 4.1: Shwoing hydrogeological zones of Uttar Pradesh

Zone	Sub zone	Approximate area (Sq.kms)
Himalayan	Lesser and central Himalayans	59,257
	Sub Himalayan or Siwalik	3,000
Inter-montane valley		1,020
Alluvial Tract	Bhabar	2,460
	Tarai	11,200
	Central Ganga plain	176,000
	Marginal Ganga plain	119,728
Vindhyan Terrain		10,468
Bundelkhand Granitic Terrain		11,280

The boundaries of these zones are approximate and more detailed studies are required for precise demarcation. However, the areas of each zone has been calculated. Hydrogeology of the above five zones is summarised in the following paragraphs.

Himalayan Zone:

The Himalayan zone has been divided into two sub-zones viz. the lesser and central Himalayan sub zones. the two sub-zones are separated by the main boundary fault.

The Himalayan zone is underlain largely by sedimentary rocks of Paleozoic to Cenozoic Era, which have been greatly deformed and metamorphosed during the orogeny of the Himalayas. The high land is dissected by deep groges and narrow valleys. The lithological units include sandstones, shales, clays and conglomerates of Neogene Siwaliks followed due north by the peletic, arenaceous and calcareous sediments and the crystalines of the central Himalayas.

Intermontane Valley:

"Doon valley" is the most prominent intermontane valley is a spindle shaped tectonic valley bordered by Lesser Himalayas in the north and Siwalik ranges in the south. The valley is underlain by unconsolidated sediments comprising boulders, cobbles, pebbles, gravels mixed with sand. Groundwater in the valley occurs under water table condition and water levels are generally deep. The static water level in the tubewells ranges from 22 meters to 76 meters below the land surface and discharge varies from 50 to 180 m^3/hour for drawdown varying from 0.7 to 8.4 meters. The coefficient of permeability of these aquifers ranges from 15 to 250 m/day.

Alluvial Tract:

The alluvial tract considered to be the most important part as the groundwater resources of the state are concerned, it is underline by unconsolidated sediments dating from Pleistocene to Recent. The Ganga alluvial tract extends in a NW-SE direction and spreads over an area of 209,388 sq.kms. This low land occupies a great crustal down-buckle formed between the mobile orogenic belt of the Himalayas and the static Peninsular shield and was filled up with the Quarternary alluvium which at places attains a thickness of more than 1000 m. This zone contains the most potential groundwater reservoir in the state. This is divided into four sub-zones viz. Bhabar, Tarai, Central Ganga Plains and Southern Marginal Plains.

i) *Bhabar or Piedmont Zone*

The nothern boundary of the Bhabar belt is generally marked by the southern edge of Siwalik hill ranges and the southern limit is characterised by the spring lines. The general width of 'Bhabar' belt ranges from 10 to 30 kms. The Bhabar belt is composed of piedmont deposits formed by lateral coalesence of fan deposits of innumerable streams emerging out of the Himalayas. Lithologically it comprises boulder, cobbles, pebbles and gravels mixed with sand. Groundwater in these deposits is mostly unconfined and water table is generally deep being 30 meters or more below land surface. Perched bodies are of common occurrence.

The tube wells down to 100 meters depth generally yield between 97 to 227 m^3/hour for drawdown varying between 2.7 and 9.7 meters. The hydraulic conductivity of the aquifer is estimated to range between 15-250 m/day.

ii) *Tarai or Wet Land Zone*

The deep water table at the foot hills cuts the land surface and gives rise to the series of springs hence this zone is called as wet land zone or Tarai. The spring line defines the northern limit of Tarai, while its southern limit imperceptibly merges with the Central Ganga plain. This is about 8 to 16 kms. wide and runs parallel to Bhabar zone. the belt is characterized by predominant clayey sediments with intercalated beds of sands and gravels. This belt is characterised by the localised occurrence of flowing conditions with piezometric heads above ground level. the top aquifers are generally unconfined and the water table is normally within four meters below land surface. The piezometric head in the flowing wells of this zone varies between 6.60 and 8.90 meters above the ground level while in the nonflowing wells it ranged between 1.65 and 11.20 meters below ground level.

iii) *Central Ganga Plain*

The northern limit of this sub zone is the southern limit of the 'Tarai'. It lies between Yamuna and Ganga rivers and extends upto their confluence at Allahabad which marks the southern limit of this sub zone. Stretching from West-north-west to east-south-east, this belt covers the major part encompassing of the Ganga-Yamuna interfluves and contain several potential aquifers down to the bed rocks. The quaternary alluvium consists of gravels and sands of various grades, silt, clay, often intercalated with calcareous concretions in varying proportions. The beds are generally lenticular and there are rapid alterations and gradations between granular and clayey horizons. The near surface groundwater is unconfined while deeper aquifers lying below 100 m are under confined to semi-confined conditions.

Depth to water level in tubewells generally ranges between 2 and 12 meters below land surface. The discharge of deep tubewells ranges between 100 and 300 m^3/hour for drawdowns of 6 to 10 meters. The pump test done in this area by various Govt. agencies reveal wide variation in permeability and transmissibility of the aquifers due to rapid change in their thickness and texture of the granular zones.

iv) *Marginal Alluvial Plain*

This subzone lies between Central Ganga plain and the region occupied by the Bundelkhand granite and Vindhyan rocks. The alluvium is composed of silt, clay and sand of various grades. Groundwater occurs both under water table and confined conditions.

In western Uttar Pradesh, this type of marginal alluvium occur at the western most margin of the region where Vindhyan rocks are exposed at a depth ranging between 220 to 280 meters (220 mts at Raya and 280 mts at Surirkalan in Mathura district). A prominent and persistent granular zone comprising fine to coarse sand with varying amount of gravel has been encountered between the depth of 30 and 170 meters in the northern part of this sub-zone.

The static water level in tubewells generally ranges from flowing conditions to 26 meters below ground level. The discharge of the tubewells varies between 60 and 240 m^3/hour for drawdowns from 3 to 16 meters.

4.2 HYDROGEOLOGIC FRAMEWORK OF THE STUDY AREA:

The area under investigation i.e. Yamuna-Karwan sub-basin is a part of Ganga-Yamuna interfluves which forms a part of the central Ganga plain. The thick pile of sediments comprising sands of various grades, silt and clay intercalated with 'Kankar', the various sand bodies form the prolific aquifers. Groundwater occurs in these saturated zones. Rainfall forms the principal source of groundwater recharge in the area, besides the surface recharge in form of irrigation return flow and numerous surface bodies like ponds and lakes in the area also contribute to the groundwater bodies through the vertical seepage. Seepage of Mat branch of the upper Ganga canal has its own importance in the area. The bottom width of this canal is 24.4 mts. with depth of 1.87 mts and bedslope is 0.15 m/km. The discharge of the canal is 21.63 cumec in the study area.

Hydrogeological Surveys:

Groundwater plays an important role in determining the water bearing and transmitting capacity of geological formations. The existing hydrogeological information, based on the work of Central Groundwater Board, Groundwater Department, U.P., was compiled and analysed. To fill in the information gap and to have a control on hydrologic system, entire study area was then covered through reconnaissance traverses.

For a proper evaluation, development and management of the groundwater resources in the study area, systematic well investigations of 93 observation wells were carried out and pertaining hydrogeological data were collected to bring out valuable informations relating to groundwater conditions and to study the changes in water levels in response to rainfall, evaporation, groundwater use and other factors. The pre and post monsoon water levels were measured in the observation wells during 1992 and 1993.

The collected data were processed and utilized in the preparation of depth to water level maps, water level fluctuation maps, and water table contour maps, etc. which bring out the potential area for further groundwater development. Besides, the lithological logs of the boreholes were collected and studied and utilized to prepare cross-sections and fnece diagram in order to depict the disposition of various aquifer systems and their lateral and vertical extensions in the area. Locations of observation wells and tubewells inventoried are shown in Fig. 4.2.

4.3 EVOLUTION OF AQUIFERS:

The evolution of aquifers in fluvial system is dependent upon the hydrodynamics of the flow regime, geology and topography of the terrain, leading to the terrigeneous clastic deposition system, which are typically represented as the channel, flood plain and back swamp deposits.

Channel Deposits:

The typical channel deposits of the river Yamuna as observed in the study area from bottom upward comprise coarse sand mixed with gravel through medium to fine sand to silt and finally capped by a thin clay layer at the top. This top clay and some fine sand layers are washed away during successive flood periods and a fresh body of sand with the fining upward sequence is deposited again each year during the flood, forming thereby a reasonably thick terrigenous clastic deposits till the river changes its course due to some tectonic control through convulsion. These thick bodies of sand form the potential repositories of groundwater or the most potential aquifers.

Flood Plain Deposits:

During the flood season when the flood water overflows the banks, medium to fine sand bodies of moderate thickness and limited areal extent are deposited over the flood plain. These lenticular bodies of sand form the moderately potential aquifers in comparison to the highly potential aquifers of the channel deposits. The lenticular shape of the aquifers is due to the fact that flooding takes place in a limited stretch of the river bank at a time.

Back Swamp Deposits or Oxbow Lake Deposits:

The flood water from the high banks further moves down the slope towards the low lying areas where it is left predominantly with the suspended material which get settled under the influence of gravity and form a lensoid body of sand which is further overlain by the still finer clasitics i.e. clay. Thus there occurs enclaves of sand bodies intercalated within the underlying and overlying clay beds. Such bodies of sand characterise the back swamp environment and form the low potential aquifers, very often associated with the quality problem. The enclosed nature of such aquifers obstruct the regular flushing or recharge rendering thereby to poor quality formation of water.

Thereafter, the river changes its course under tectonic control through convulsion or some other factor like earth quake etc. Thus with the passage of time, the position of channel, flood plain, and back swamp deposits also continue changing. That is why that no continuous body of sand or clay except under certain extraordinary situation in a single bore hole. Thus the lithological variations are attributed to their mode of deposition by the constantly shifting nature of the river Yamuna and other streams draining the study area.

The various aquifer systems, thus generated by the river Yamuna and Karwan are as under:

a) The channel deposits are thick bodied aquifers of infinite areal extent forming most potential ground-water reservoir.

b) Flood plain deposits giving rise to the lenticular type of aquifers of limited thickness and areal extent and are only moderately potential.

c) Lensoid bodies of sand occurring as enclaves or stringers within the thick clay beds, generally form the low potential aquifers often with quality problems.

In a thick Yamuna alluvium, the complexes of the channel, flood plain, and back swamp facies reappear several times in a well drilled at places in the area. Thus the terrigenous clastic depositional system of the river Yamuna in the study area is an index of its complex hydrodynamic regime which generated various aquifers in the sub-basin.

4.3.1 Delineation and System of Aquifers:

In order to ascertain the sub-surface geological framework and aquifer disposition in the study area, the

Fig. 4.2: Map showing the area surveyed Dug-wells and tubewells inventoried in Yamuna-Karwan Sub-basin.

lithological logs of the boreholes of the existing tubewells drilled by the state Tubewell Department in the area (Appendix II) were utilized to prepare the fence diagram (Fig. 4.3) and hydrogeological cross-sections along the lines AA', BB', CC', DD' and EE' (Fig. 4.4a to 4.4e). The location of these lines are shown in Fig. 4.2.

The fence diagram reveals the vertical and lateral disposition of aquifers, aquicludes and aquitards in the study area down the depth of 92.0 metre b.g.l. A perusal of fence diagram shows that in all there occurs two to three tier aquifer system down to the depth of 92.0 m.b.g.l.

In northeast portion adjacent to the Karwan river the aquifers appear to merge with each other and behave as a single bodied aquifer system with the maximum thickness of 37.78 meters. Comprising fine through medium to coarse sand occasionally mixed with Kankar. It appears to be the channel deposits of the hydrodynamics of river Yamuna. It is also confirmed by the section A-A' and B-B', which shows that the clay beds occur simply as a lensoid body. The depth of shallow aquifers ranges between 4.0 m.b.g.l. to 35.66 m.b.g.l. The minimum depth of shallow aquifer is 4-15.25 m.b.g.l. found in eastern portion of Khair block, while the maximum depth of shallow aquifer is 35.66 m.b.g.l. in the central portion of the study area in Tappal block and the maximum depth of shallow aquifer in Nojhil block is 25.50 m.b.g.l. The shallow aquifers are under the water table condition while the deeper aquifers have been identified as leaky confined in character. The deeper aquifers behave as a single bodied aquifer. The shallow and deeper aquifers are separated with clay bed intermixed with silt and Kankar which serves as an aquitard.

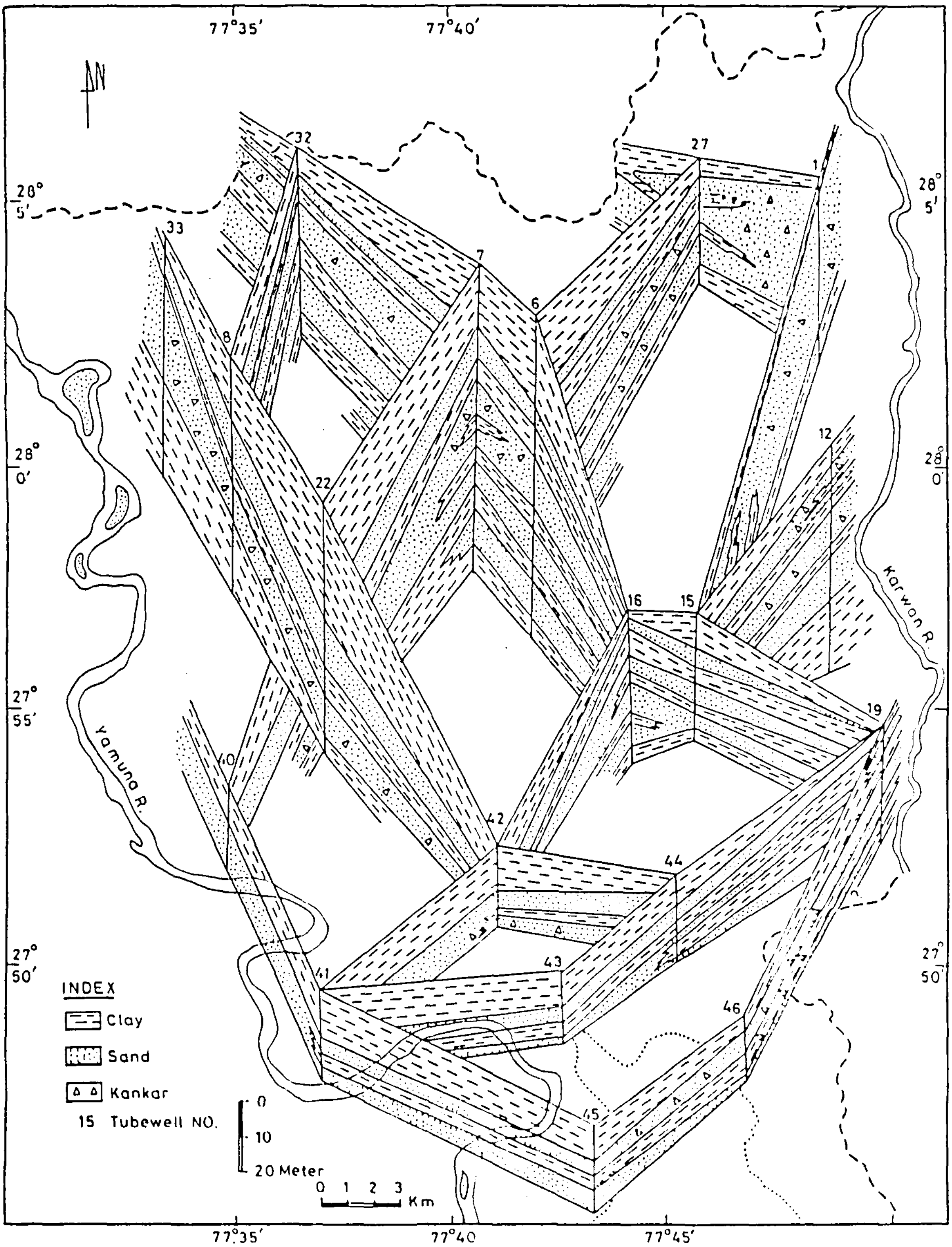


Fig. 4.3: Fence diagram of the area showing aquifer disposition.

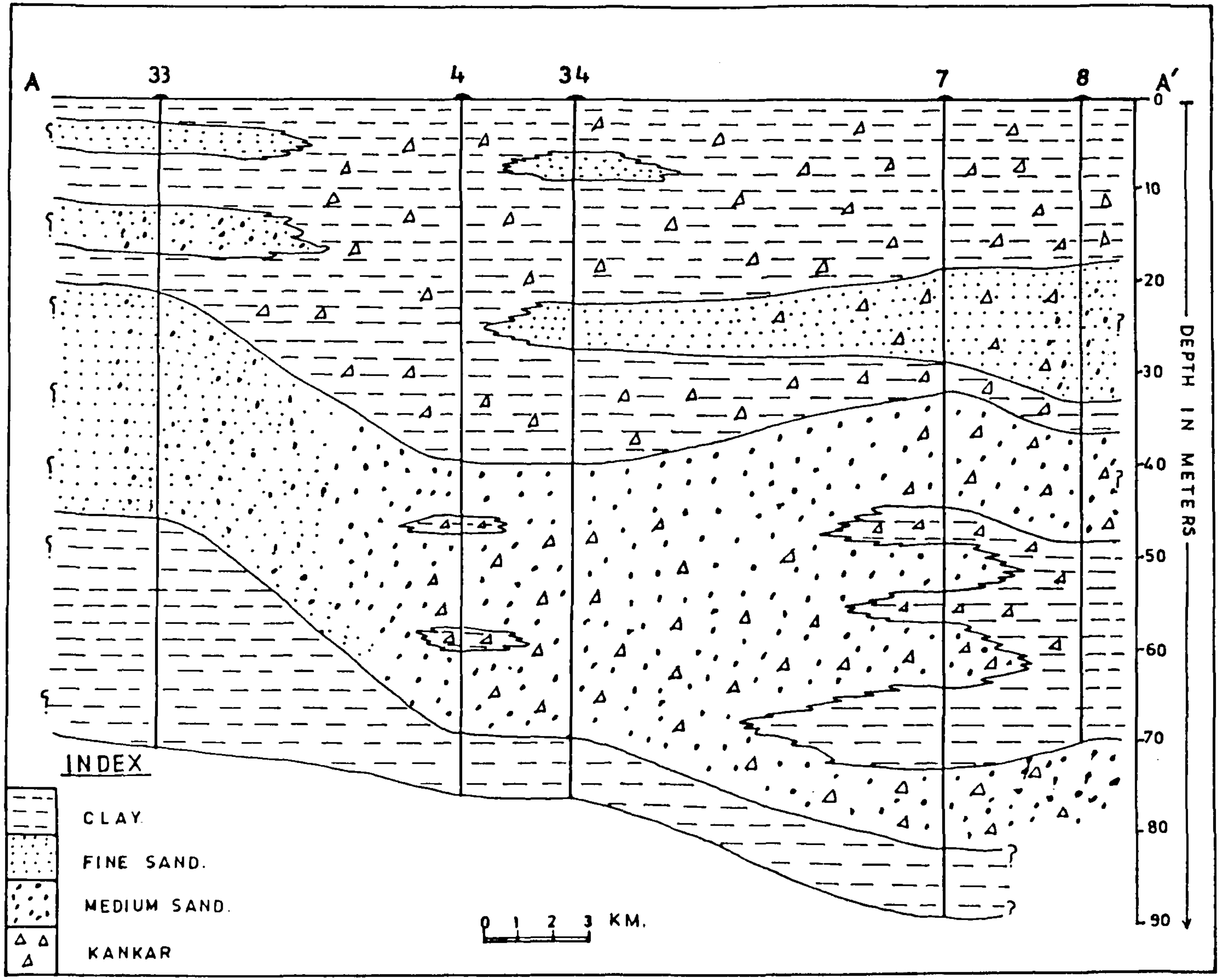


Fig. 4.4a: Hydrogeological cross-section along line A-A'.

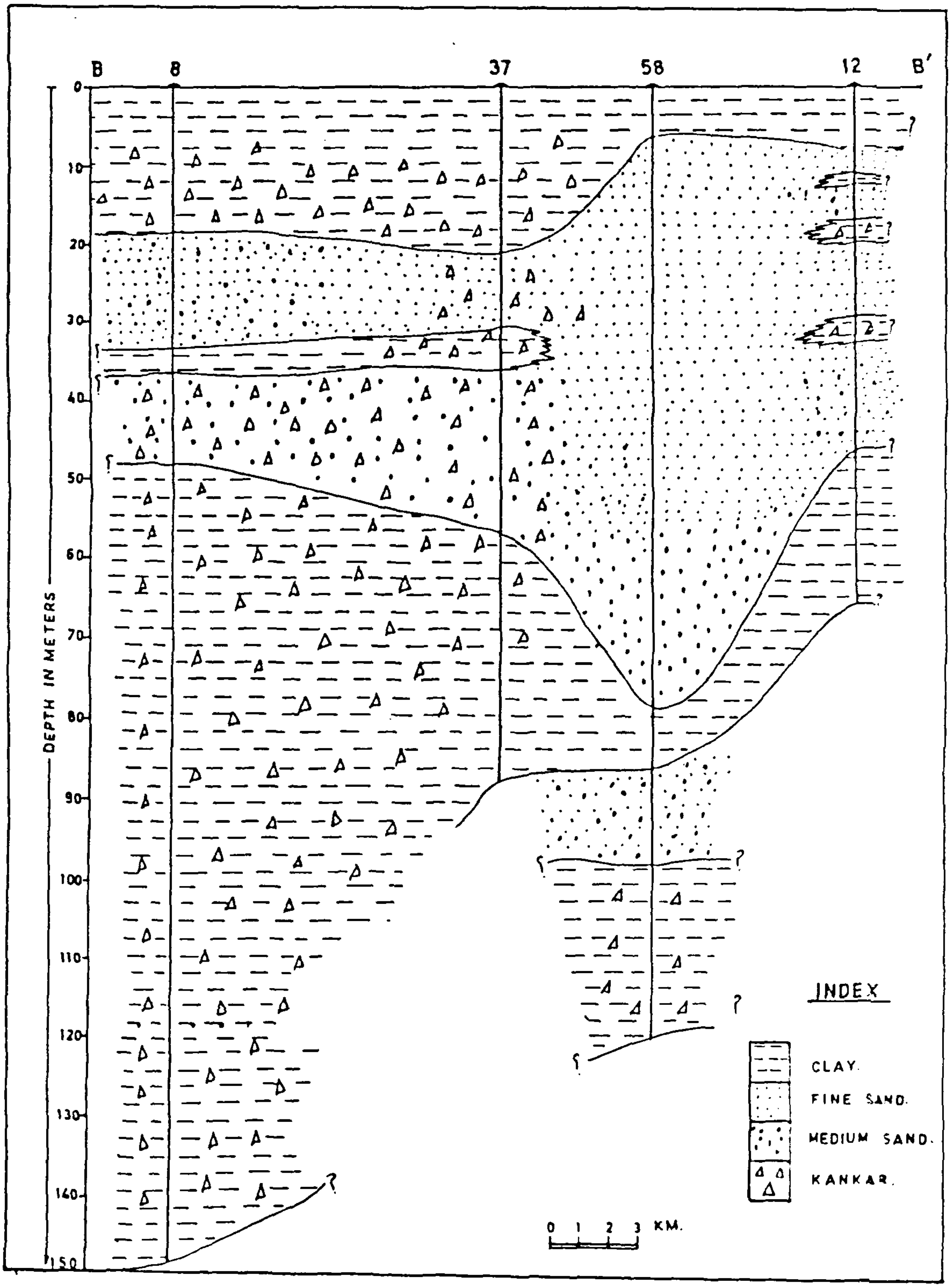


Fig. 4.4b: Hydrogeological cross-section along line B-B'.

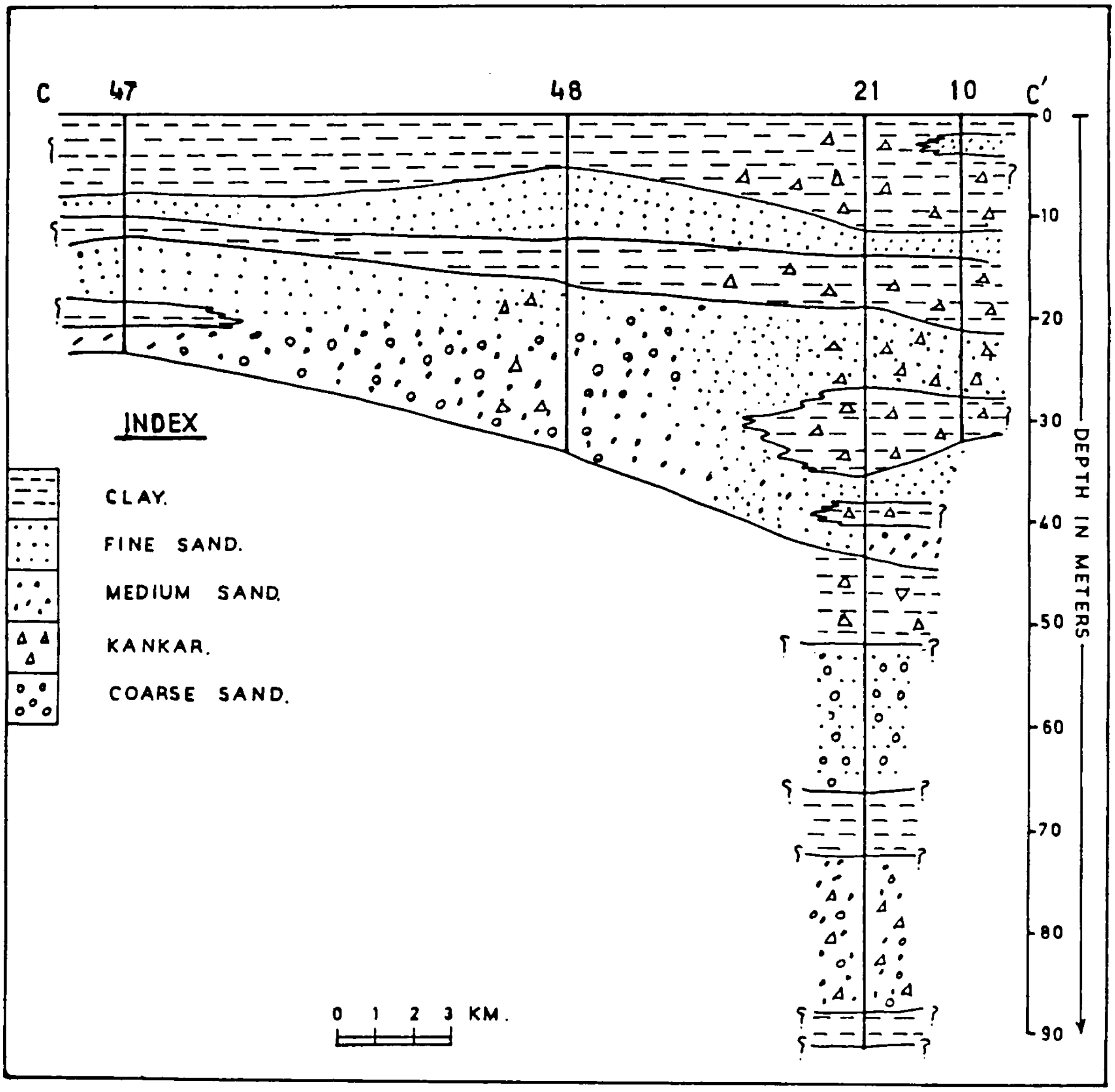


Fig. 4.4c: Hydrogeological cross-section along line C-C'.

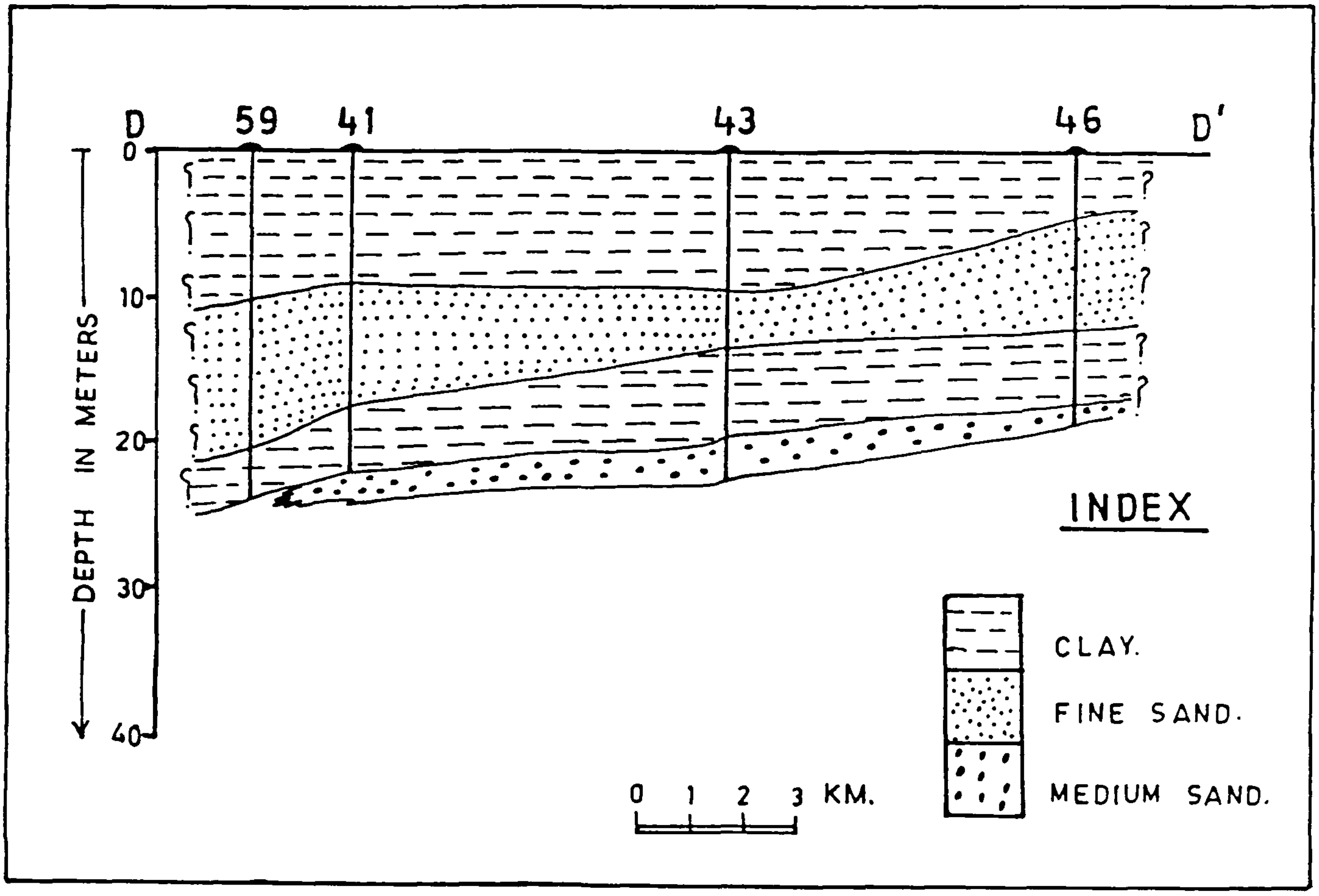


Fig. 4.4d: Hydrogeological cross-section along line D-D'.

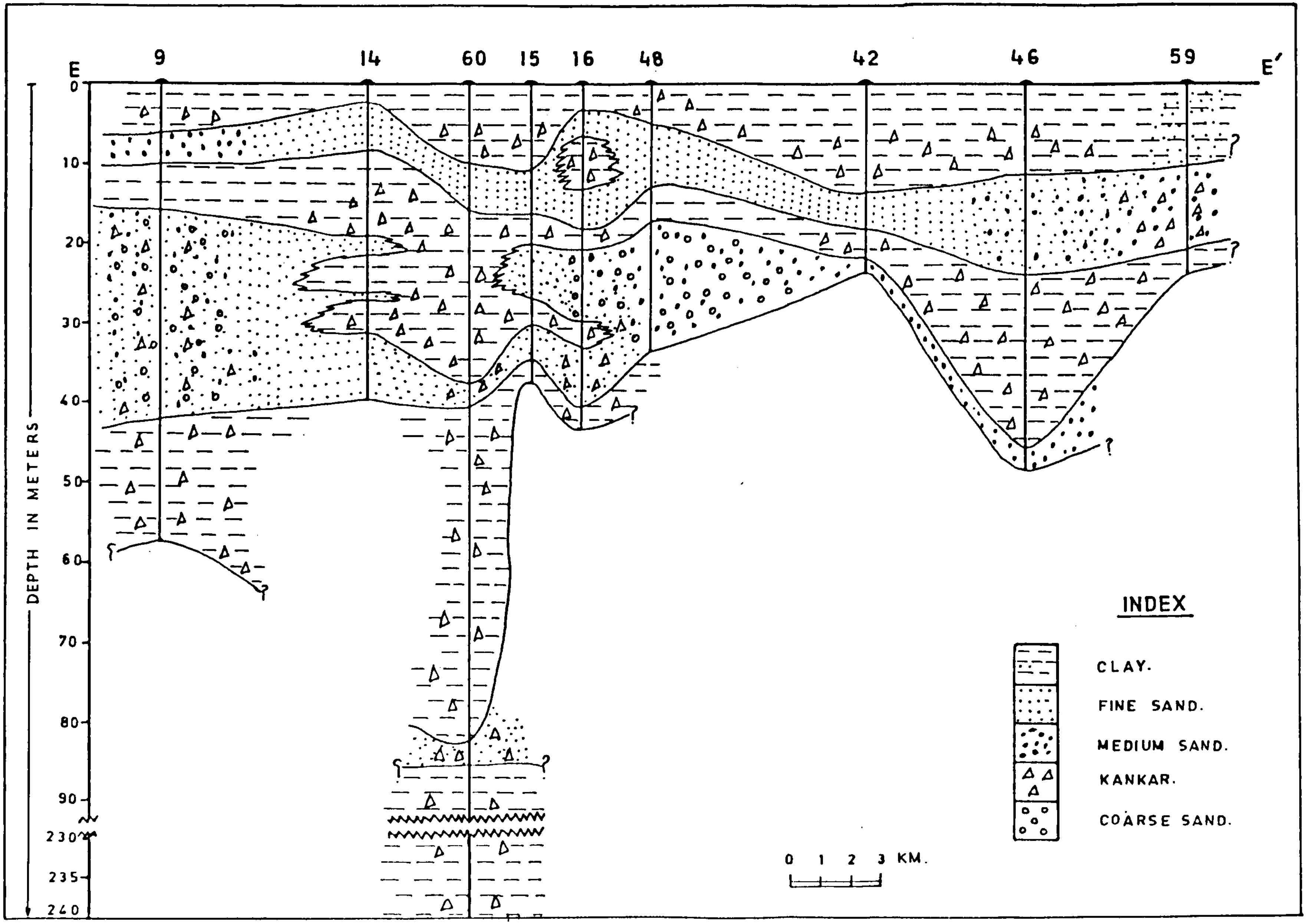


Fig. 4.4e: Hydrogeological cross-section along line E-E'.

From east to west direction the clay beds gradually start attaining thickness and occur in repeated alternation with the granular zones. the percentage of granular zone is around 40 to 50% and it appears to be the flood plain deposit. It is also revealed by the hydrogeological sections which shows alternate sand and clay beds where the clayey horizons gradually pinch out. Similar position is observed in the central part of the area too. The most peculiar sub-surface hydrogeological set up is found in the SE and SW parts of Nojhil and Khair blocks, where the clay predominates over the sand. The granular zone here comprises 30 to 40% of total lithounits. These appear most probably as back swamp deposits which also possess the quality problem.

4.4 DEPTH TO WATER LEVEL:

In an unconfined aquifer, the water level is the upper surface of the zone of saturation where the pressure is atmospheric. It is defined by the level at which water stands in wells penetrating the aquifer, just enough to hold standing water. However, in general the water level standing in dugwells are considered accurate enough to represent water level of an area. The depth to water level map depicts the regional variations of the water level with respect to land surface all over the area.

Based on the data collected from the field observations of static water levels in the shallow well during June and November, 1992 (Appendix III) and June and November, 1993 (Appendix IV) depth to water level maps of pre-monsoon and post-monsoon periods have been prepared (Fig. 4.5, 4.6, 4.7 and 4.8).

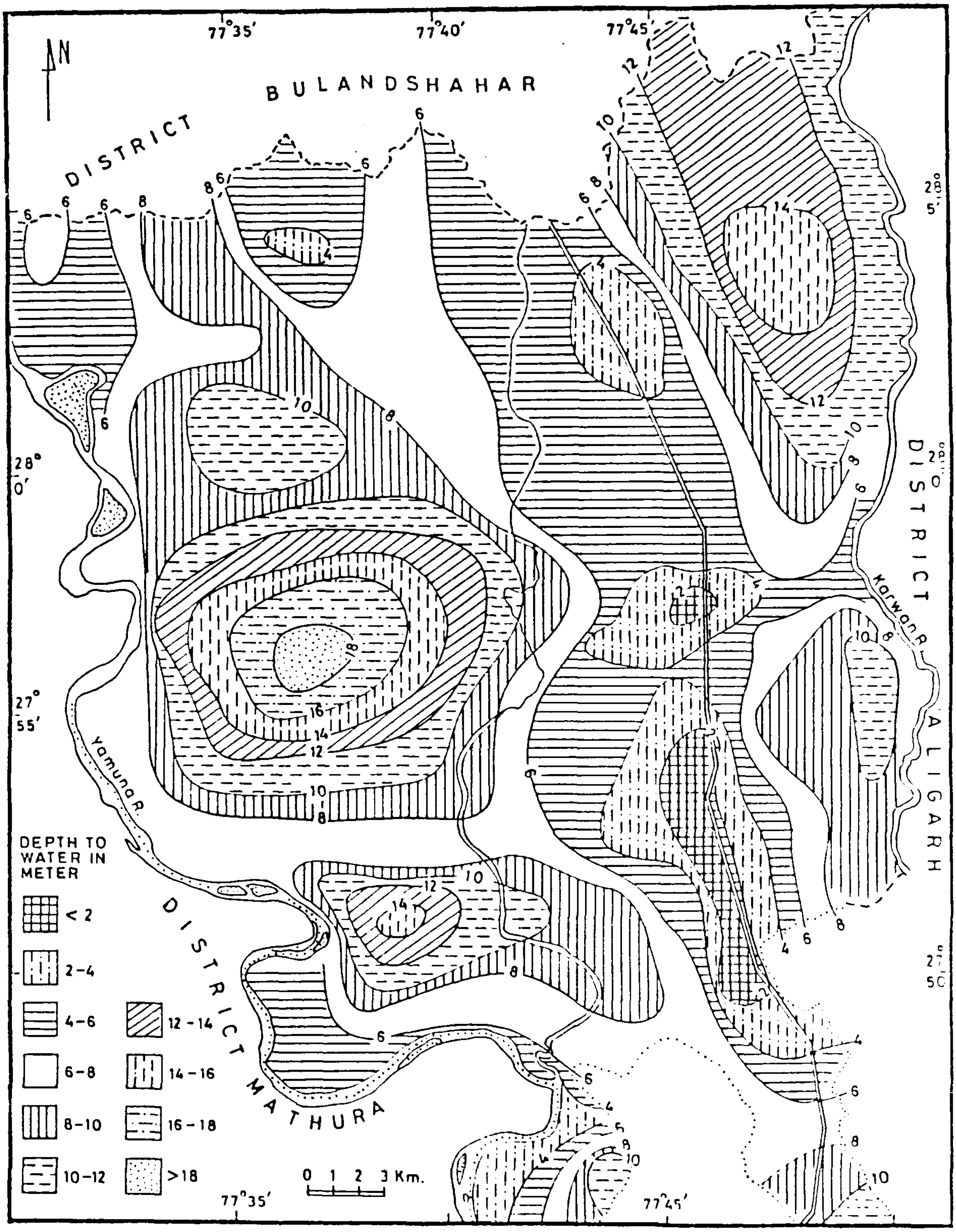


Fig. 4.5: Pre-monsoon depth to water map, June 1992.

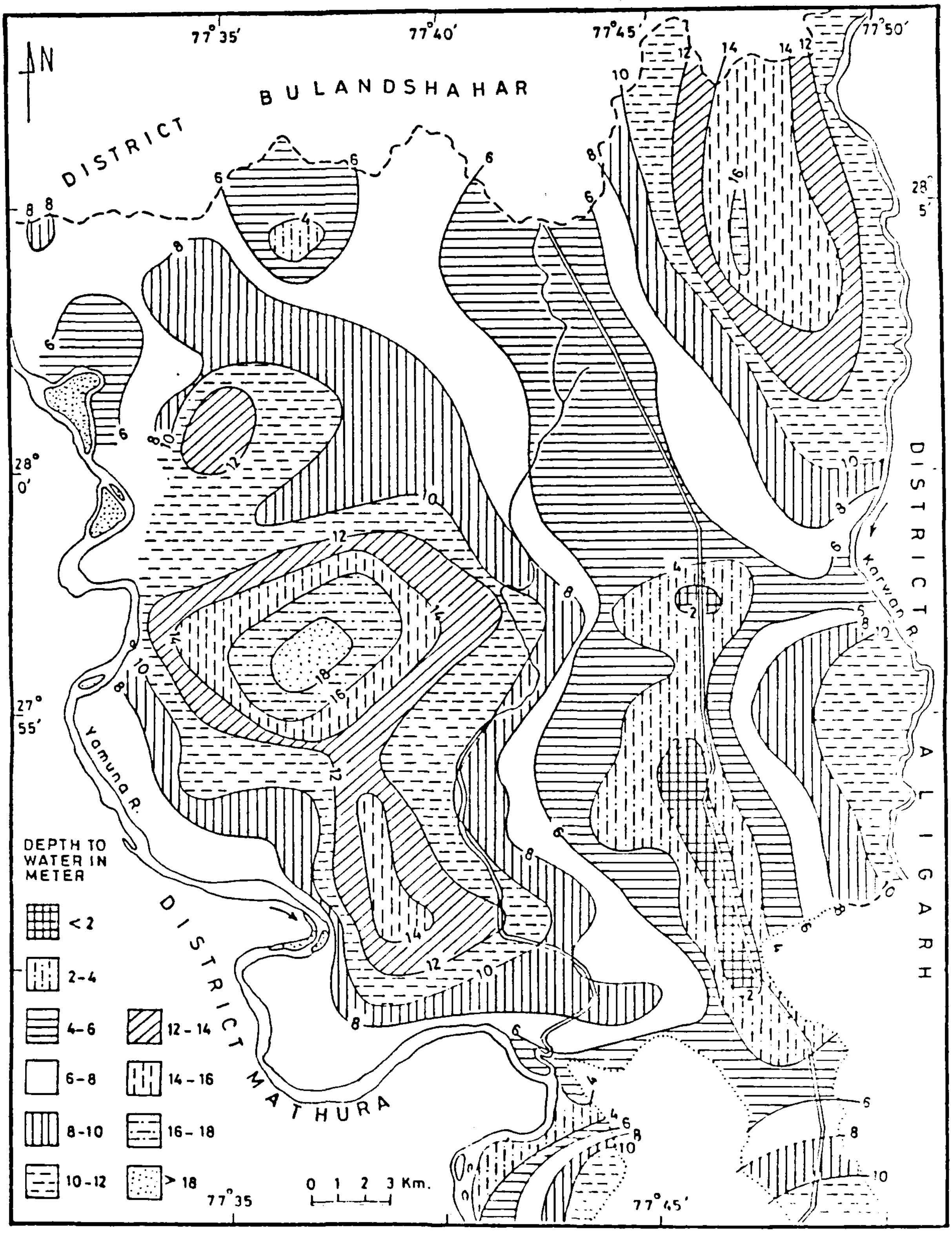


Fig. 4.7: Pre-monsoon depth to water map, June, 1993.

4.4.1 Depth to water level (pre-monsoon, 1992, 1993):

In pre-monsoon (1992, June) the depth to water ranges between 1.20 to 18.52 meters below ground level, while in June 1993 it ranges between 1.15 to 18.70 meters below ground level (b.g.l.). The area has been divided into 10 depth to water level zones varying from (1) upto 2 (2) 2-4 (3) 4-6, 94) 6-8, (5) 8-10, (6) 10-12, (7) 12-14, (8) 14-16, (9) 16-18 and (10) more than 18 meters below the ground level (Figs. 4.5 and 4.7).

The deeper levels viz. 19.0 and 19.72 m.b.g.l. were recorded at Ghagauli village in June 1992 and 1993, respectively while shallowest water levels viz. 1.20 and 1.15 m.b.g.l. were recorded at village Mayaramgarhi adjacent to the Mat canal in the 1992 and 1993, respectively.

A perusal of maps shows that depth to water level is increasing towards eastern upland along the Karwan river where it ranges between 8 to m.b.g.l. and in western parts of the study lying between Yamuna river and Patwah drain the depth to water level ranges between 8-19 m.b.g.l.

In the vicinity of Mat canal, the depth to water level is generally shallow which ranges from less than 2 to 6 m.b.g.l. Two patches have been demarcated water logged area around Nagla, Mayaramgarhi, Pachara, Bhureka and Moinuddinpur where the water level ranges between 1.15 to 2.0 m.b.g.l. which is the resultant effect of the quantum of seepage that has been taking place ever since the commissioning of the Mat canal. The excessive seepage is taking place through the unlined canal beds and consequently

Table 4.2a: Depth to water level (June 1992, 1993)

Year	No. of well	Depth to water range (m.b.g.l.)										
		Dry	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20
1992	93	5 5.37%	5 5.37%	11 11.82%	23 24.73%	10 10.75%	15 16.12%	9 9.67%	9 9.673	4 4.30%	nil -	2 2.15%
1993	93	8 8.60%	6 6.45%	8 28.60%	22 23.65%	12 12.90%	16 17.20%	9 9.67%	6 6.45%	3 3.22%	1 1.07%	2 2.15%
Average %		6.98	5.91	10.21	24.19	11.82	16.66	9.67	8.06	3.76	1.07	2.15

Table 4.2b: Depth to water level (November 1992, 1993)

Year	No. of well	Depth to water range (m.b.g.l.)										
		Dry	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20
1992	93	2 2.15%	9 9.67%	22 23.65%	11 11.82%	14 15.05%	15 16.12%	9 9.67%	4 4.30%	5 5.37%	Nil -	2 2.15%
1993	93	nil	6 6.4%	16 17.20%	19 20.43%	11 11.82%	11 11.82%	18 19.35%	6 6.4%	4 4.30%	1 1.07%	1 1.0%
Average %		2.15	8.03	20.42	16.12	13.43	13.97	14.51	5.35	4.83	1	1

the general water level in the area proximal to the canal has progressively been rising.

It is observed that the eastern upland is facing water logging situation due to excessive seepage while, the western part shows the declining trend of water level due to heavy withdrawl of groundwater through shallow and deep tubewells. The table 4.2a shows number and percentage of wells falling in different depth to water zones.

It may be observed from the tables 4.2a & b that during pre-monsoon period, 50.51% of wells show depth to water level ranging between 6 to 16 m.b.g.l., 2.15% of wells ranges between 16 to 20, m.b.g.l., 36.55% of well 2-6 and 5.37% of the wells showing less than 2 m.b.g.l. Similarly during post-monsoon period, 49.44% of well are showing the depth to water level ranging between 6-16 m.b.g.l., 3.22%, 16-20, 32.25% wells, 2-6 and 6.45% of the wells showing less than 2 m.b.g.l.

A comparison of the tables 4.2a & 4.2b shows that the percentage of wells recording depth to water less than 2 meters is increasing by 4.30% during the post- monsoon in the year 1992 but during 1993 it decreases by 0.05%, and there is decrease by 5.37% in the value of wells recording the depth to water more than 12 m.b.g.l. during the year 1992 but no significant change have been observed during 1993. The change during 1992 can be attributed to the recharge of aquifers through rainfall but due to less rainfall during 1993.

4.4.2 Post Monsoon depth to water level:

Figures 4.6 and 4.8 show the depth to water level of post monsoon (November, 1992 and 1993).

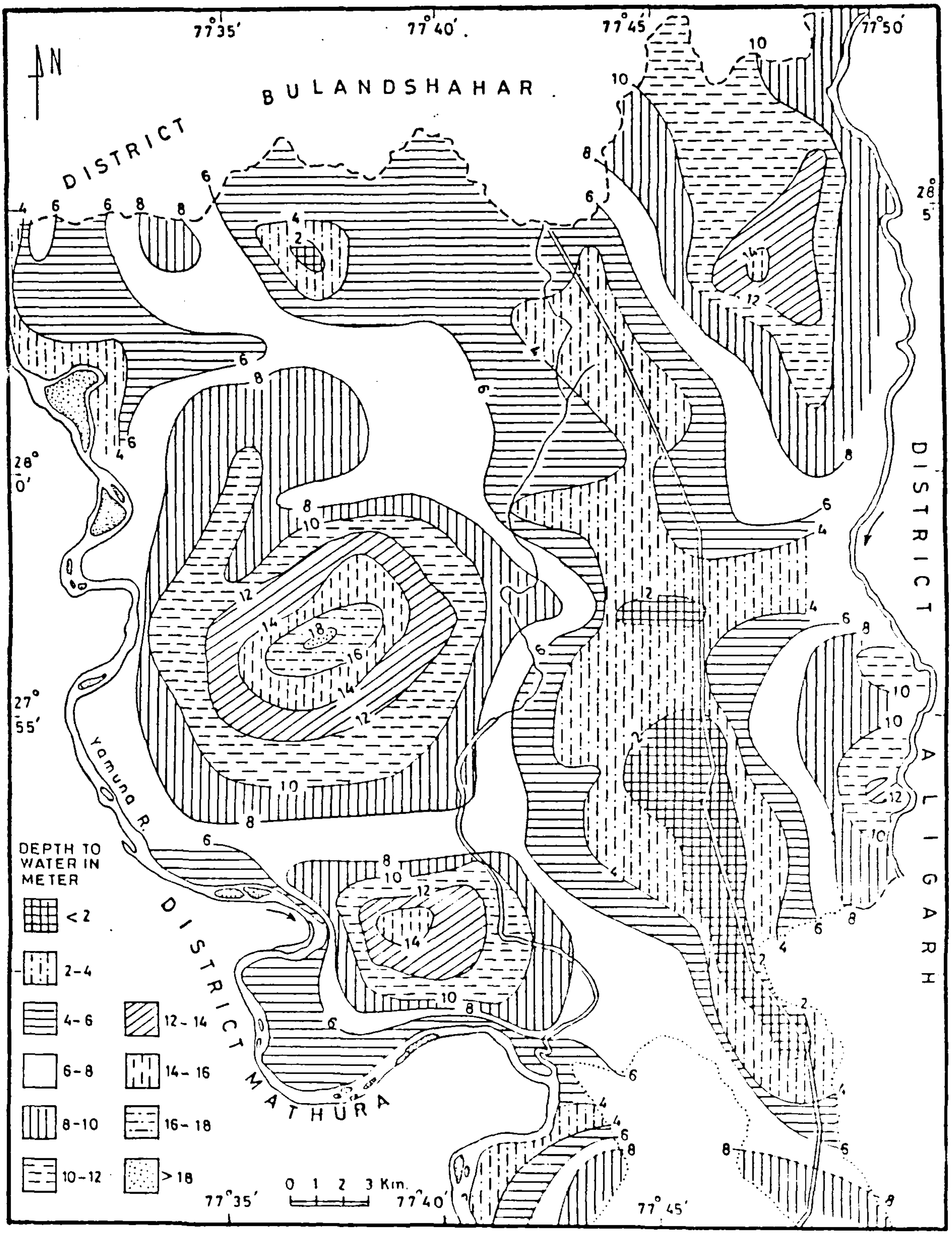


Fig. 4.6: Post-monsoon depth to water map, November, 1992.

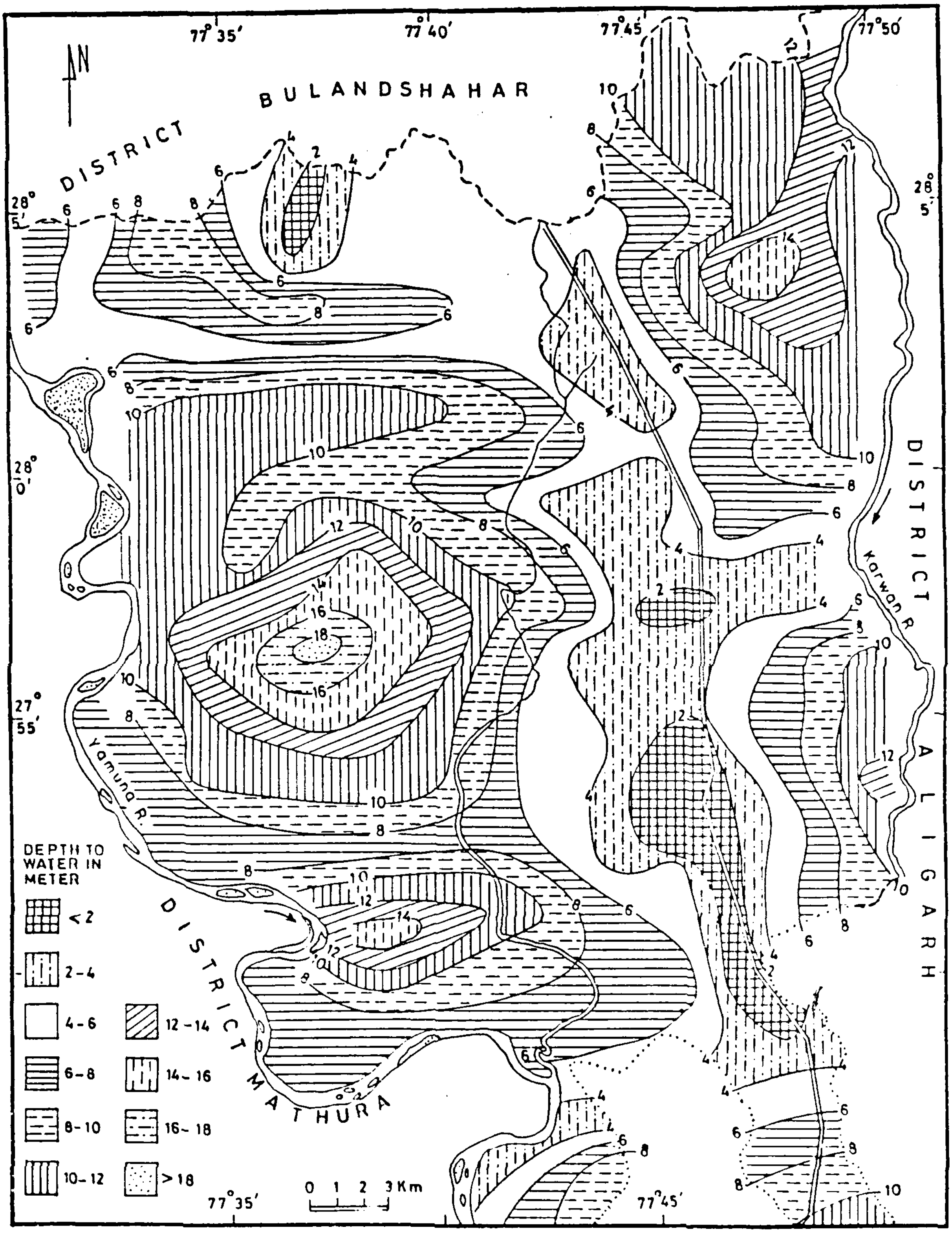


Fig. 4.8: Post-monsoon depth to water map, November, 1993.

A perusal of figures shows that during November 1992 and 1993, the shallowest water level is recorded at Pachara i.e. 0.78 and 0.74 m.b.g.l. while the deepest level i.e. 18.30 and 19.04 m.b.g.l. were observed at Ghaguali village in the western upland.

Shallow water level leading to swampy conditions during and after monsoon season is characteristic features of the low land, and Mat canal command areas. The shallow water zones lie along the Mat canal with the depth ranging between less than 2 to 6 m.b.g.l. The another depth to water level zone was observed on eastern upland along the Karwan river, where the depth to water ranges between 8 to 15 m.b.g.l. The post-monsoon depth to water level map of 1993 does not show any significant difference. This is caused due to the deficient rainfall during 1993.

In general depth to water zones described are found in confirmity with the general physiographic units of the area.

4.5 WATER LEVEL FLUCTUATION:

The groundwater level fluctuation is a function of time and space in response to precipitation. The change in water levels are due to the change in storage of groundwater in an area. It can also be caused due to excessive withdrawl of water from the aquifer than the quantum of the average annual recharge.

The water level fluctuation maps (Fig. 4.9 and 4.10) have been prepared for the period of 1992 and 1993 by way of

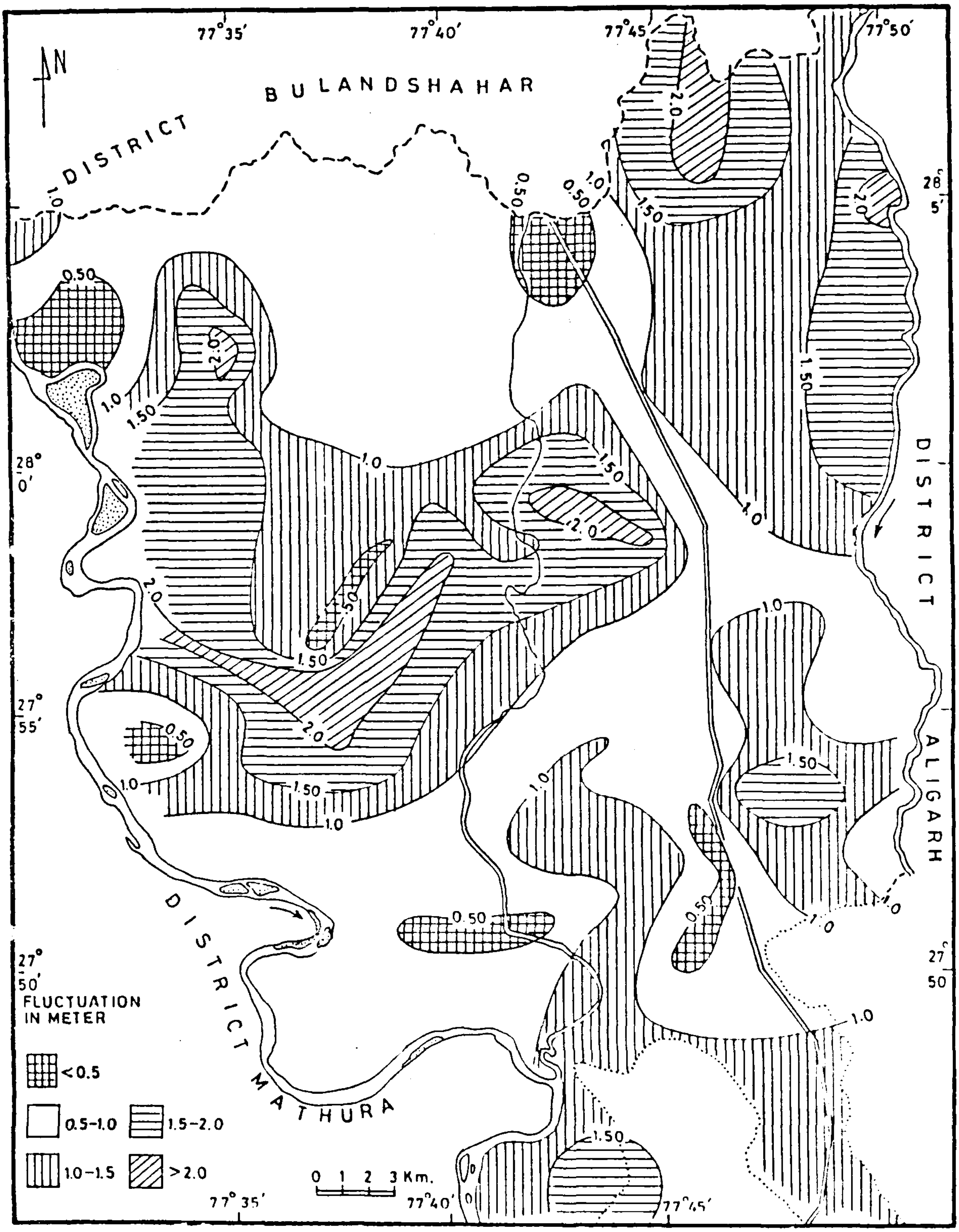


Fig. 4.9: Water level fluctuation map of the study area, during the year 1992.

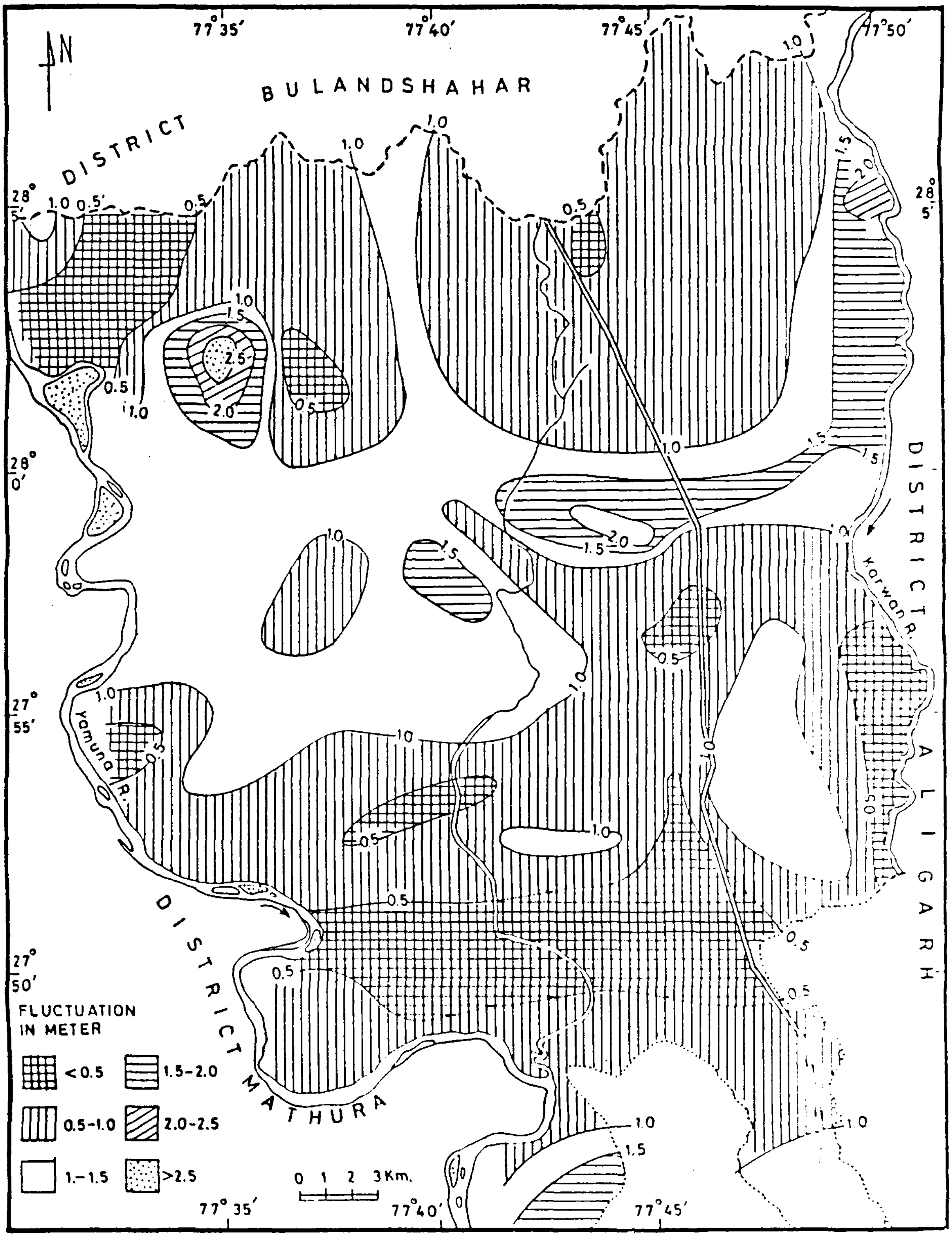


Fig. 4.10: Water level fluctuation map of the study area during the year 1993.

contours of water level difference in pre-monsoon and post-monsoon water levels. This difference in groundwater level show a seasonal pattern of fluctuations. This results from influence such as rainfall and irrigation pumping that follow well defined seasonal cycles (Todd, 1980). A perusal of fluctuation maps (Fig. 4.9 & 4.10) shows that with an interval of 0.50 m, the area is divisible into 0-0.5 (2) 0.5-1.0, (3) 1-1.5, (4) 1.5-2.0 and (5) 2-2.5 meters water level fluactuation zones. Table 4.3 gives the number of wells falling in different fluctuation zones.

Table 4.3: Shwoing range of flucatuation in percent

Year	No. of wells	Fluactuation range (m)				
		0-0.5	0.5-1	1-1.5	1.5-2.0	2.0-2.5
1992	88	13	30	25	8	12
		14.77%	34.09%	28.40%	9.09%	13.63%
1993	85	26	31	17	7	4
		30.58%	36.47%	20.00%	8.23%	4.70%

The table 4.3 shows that in the major part of the area the fluctuation ranges between 0.5 to 1.0 meter and is followed by the zone showing fluctuation in the range of 1 to 1.5 m in 1992 and 0 to 0.5 in 1993. While the fluctuation of 0.5 m was recorded only 14.77% during 1992. The difference in fluctuation of 1992 and 1993 shows that the recharge of the groundwater was less in 1993. The variation in fluctuation in the low lying areas close to the feeder canal (Mat branch) is probably due to the constant recharge of the top aquifers through verticle seepage leading to the rise of water table above the ground level.

It is very interesting to note that this water above the ground surface be really called surface water or groundwater above the ground level. The literature is full with the defined difference between the two as the water above the zone of aeration is surface water and that below it is the groundwater. So far my knowledge goes nobody has ventured to define this groundwater which rises under the impact of rampant seepapge of surface water into the aquifer below the canal beds.

High fluctuation areas (upland areas) are recharge areas and the less fluctuation areas (low land) are the discharge areas as the same is apparent from the above discussion. The fluctuation map of 1993 (Fig. 4.10) does not show any significant change in water level. this is caused due to scanty rainfall during the year 1993.

4.6 GROUNDWATER MOVEMENT:

Groundwater is invariably moving. This movement is governed by established hydraulic principles (Todd, 1959). Groundwater moves in the direction of slope of water table and the slope of water table in turn depends upon many factors such as permeability and thickness of water bearing zone, the topography, lithology and local variations in the quantity of recharge and discharge (Hubbert and Toth, 1962).

4.6.1 Water Table Contour Maps:

Water level data of wells collected during pre-monsoon and post-monsoon (1992, 1993) have been analysed and altitudes of water level with reference to the mean sea level were worked out. For this purpose, all the observation wells were connected with survey of India Bench Marks, wherever available. The reduced levels of water table with reference to mean sea level were plotted on a map and water table contour maps were prepared with contour interval of two meters (Fig. 4.11, 4.12, 4.13 and 4.14).

The water table contour maps are very useful in decipharing the groundwater flow direction, hydraulic gradient and area of recharge and discharge. Convex contours indicate area of groundwater recharge, while concave contours show tract of groundwater discharge (Todd, 1980). further, the divergence of flow lines indicates a recharge area whereas convergence of flow lines depicts the discharge area (Fetter, 1980).

4.6.2 Form and slope of water table:

A perusal of pre-monsoon water table contour maps (1992, 1993 (Fig. 4.11 and 4.13) shows the elevation of water table ranges between 190 meters in north-west parts to 162 meters in the south-east above the mean sea level. The general groundwater flow in consonance with the regional groundwater flow direction in the central Ganga basin is from NE-SE direction. However, at places there are some variations which are caused due to local factors.

In eastern flank the groundwater flows towards Karwan rivers, which shows the effluent nature of this river. Similarly, the Patwah drain is also receiving the groundwater in the central part of the study area. The river Yamuna receives groundwater runoff all along half of its northern stretch and along its southern most stretch and thereby behaves as an effluent stream. However, the river

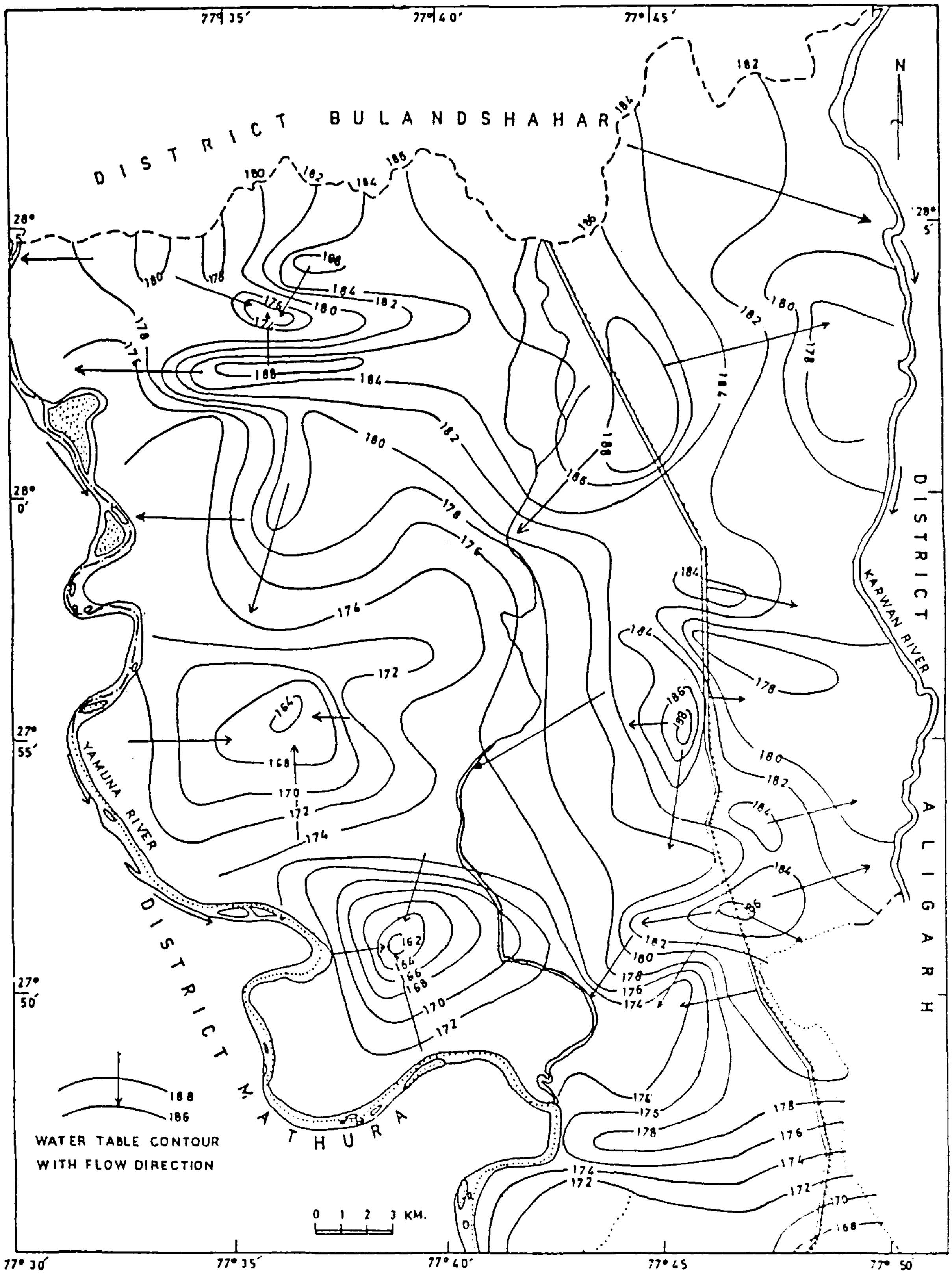


Fig. 4.11: Pre-monsoon water table contour map, June, 1992.

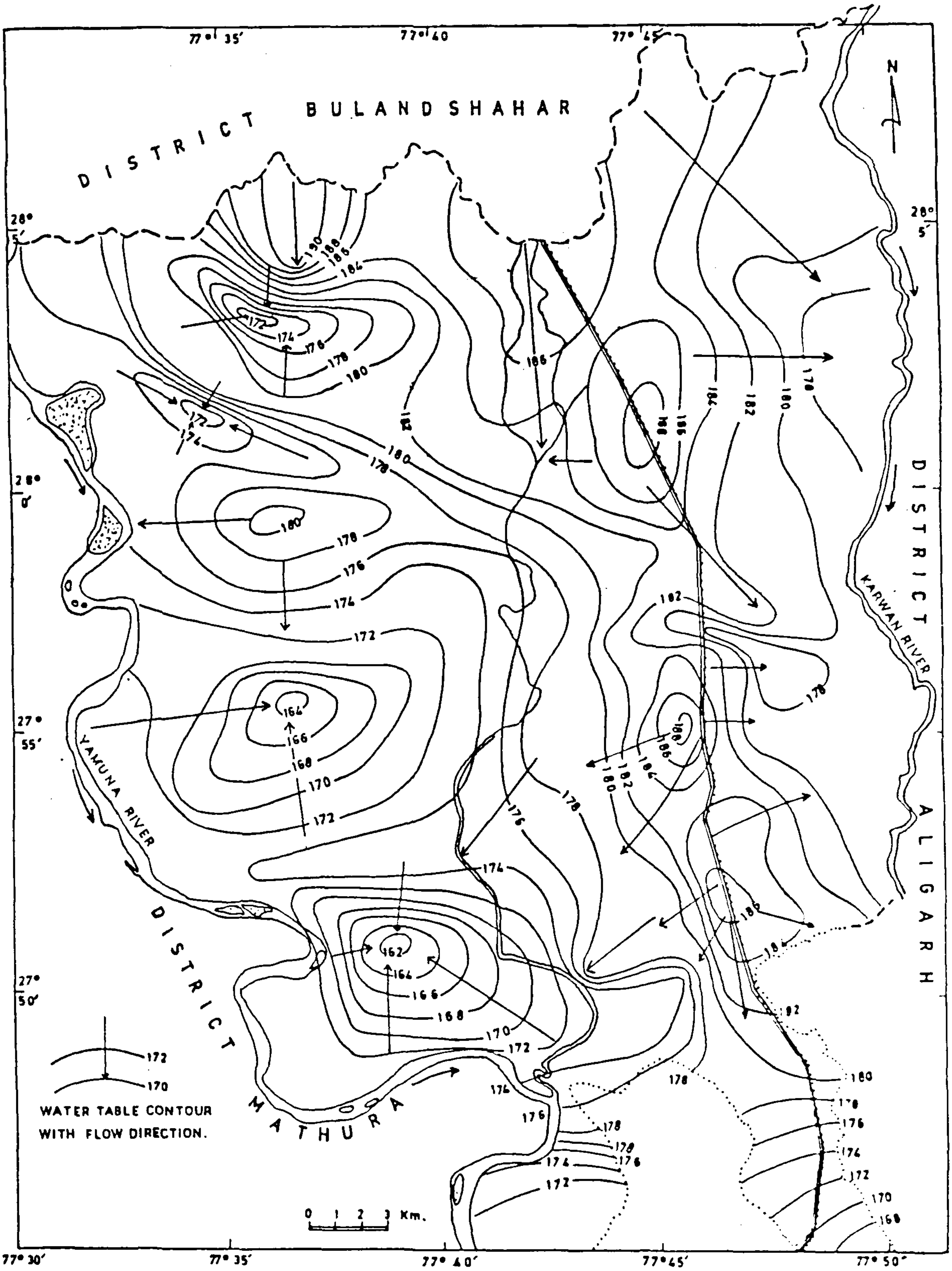


Fig. 4.13: Pre-monsoon water table contour map, June, 1993.

Yamuna recharges aquifers at some places and behaves as an influent stream as is evident from the troughs which are formed around Nurpur, Mangarhi and Nojhil along the Yamuna river. These troughs are the resultant effect of over development or heavy withdrawl of groundwater through the huge number of shallow formers tubewells as there are no canal in these areas except Jarara distributary of Mat feeder canal at Nurpur (transperancy showing canal network can be superimposed over the map), which is not recharging the aquifer commensurate to the water withdrawl.

Three groundwater mounds appear to have formed around Amangarhi, Ahrola, Khera, Edalpur and Bhureka along the Mat feeder canal. Which is caused due to the rampant seepage of water into shallow aquifers through unlined canal beds. Similarly, a mound has also developed at Naglakura and Udaipur villages along Jewar distributary.

The hydraulic gradient in the study area varies from 0.50 m/km in general to 2.5 m/km all along the Mat feeder canal and at few places in the north western end of the area. The steep hydraulic gradient is indicative of low permeability horizons (Todd, 1980).

4.6.3 Post-Monsoon Water Table Contours:

Maps (Figs. 4.12 and 4.14) show the post-monsoon water table contours for the period November, 1992 and 1993. The post-monsoon water table contour values remain essentially the same because of low fluctuation in water table.

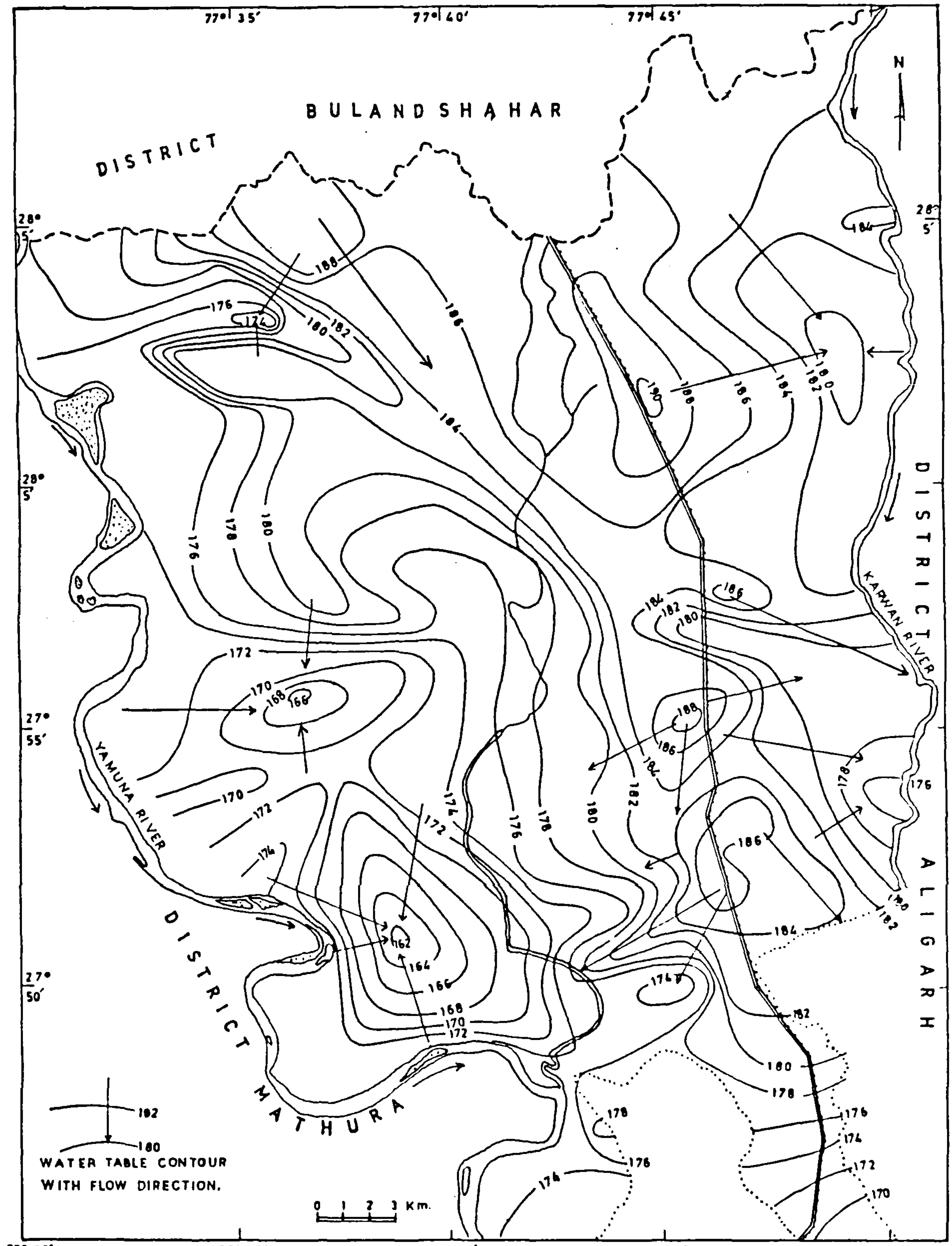


Fig. 4.12: Post-monsoon water table contour map, Nov., 1992.

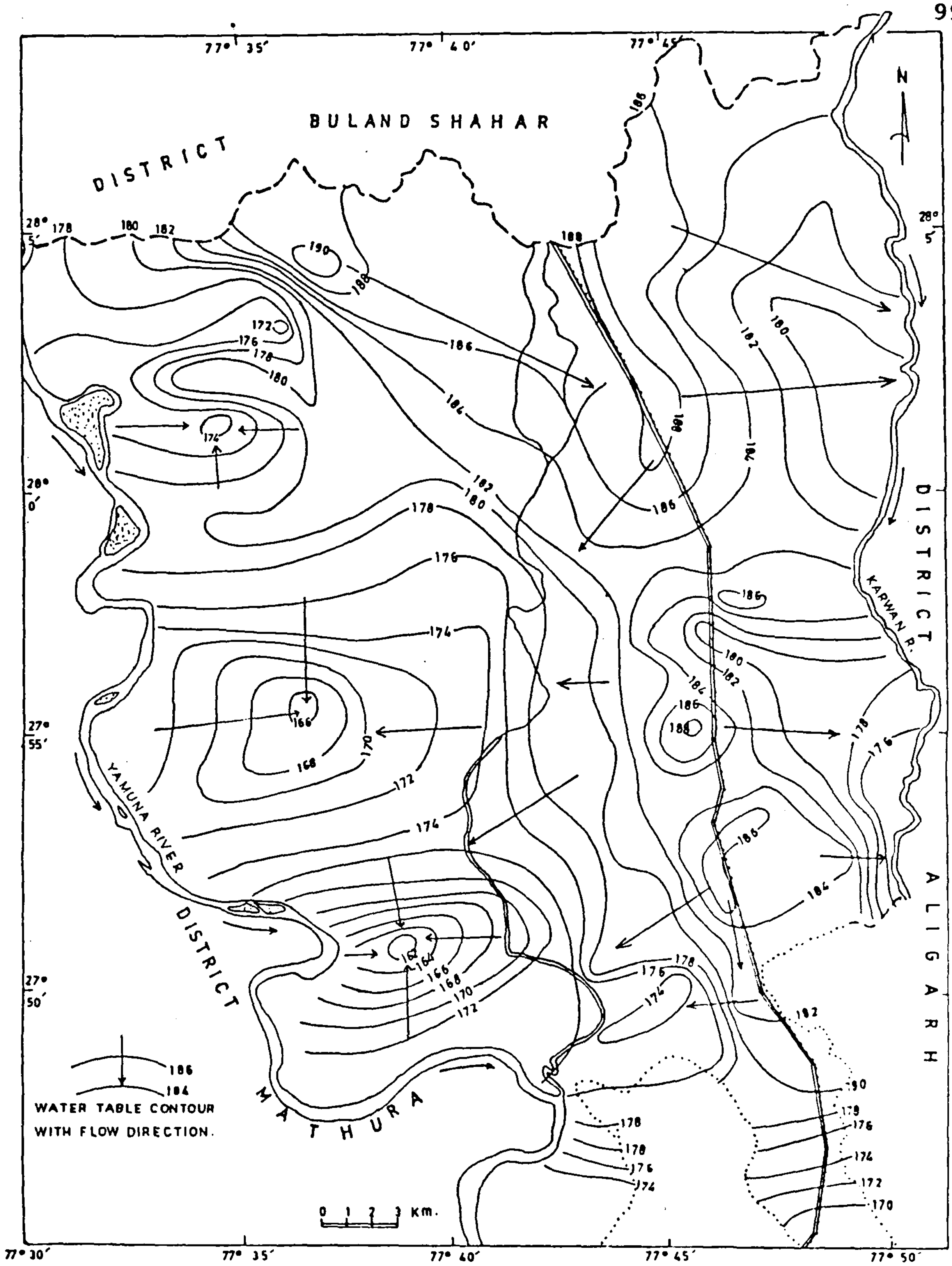


Fig. 4.14: Post-monsoon water table contour map, November, 1993.

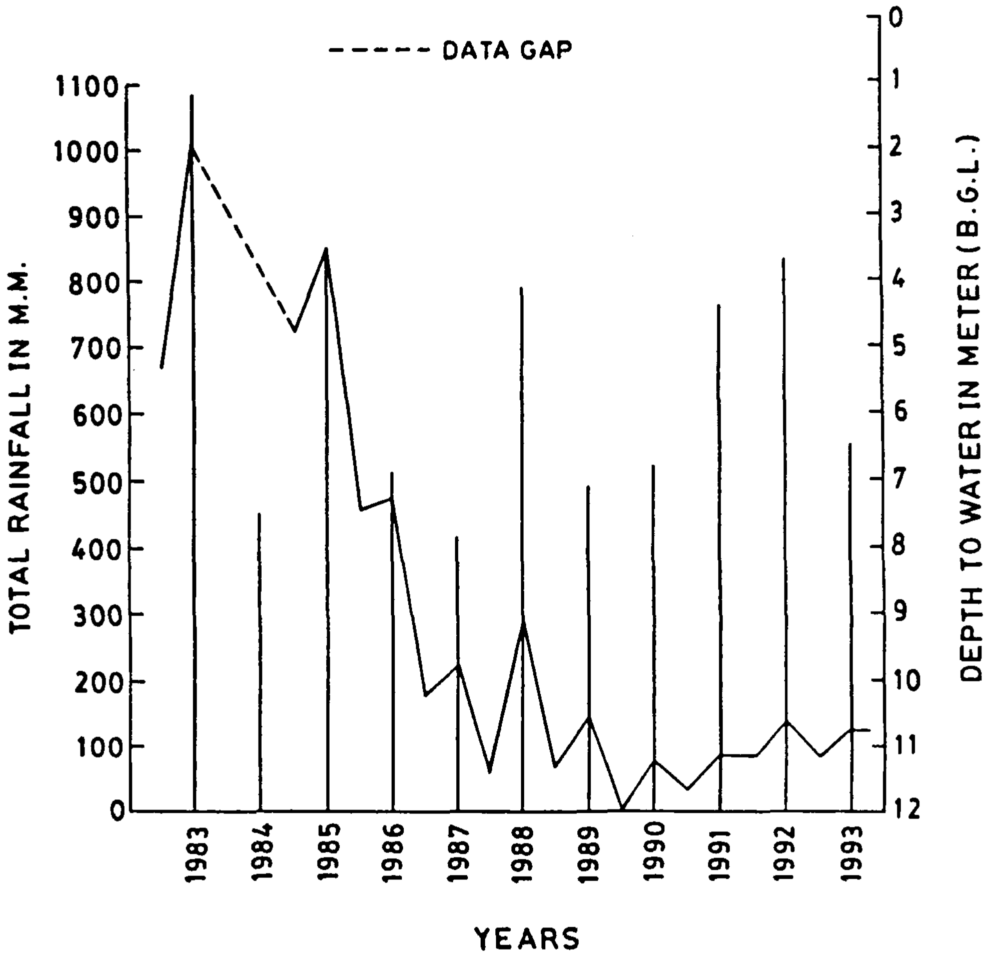


Fig. 4.15a: Hydrograph of Khair observation well.

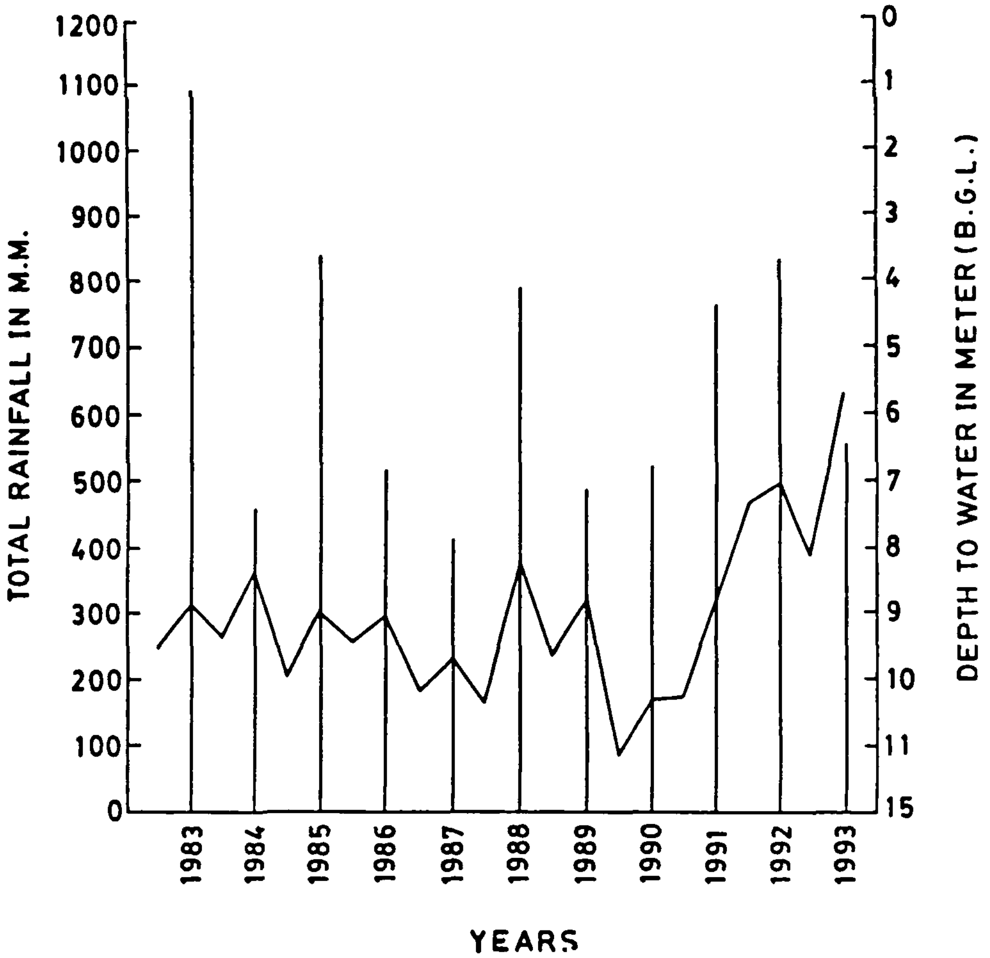


Fig. 4.15b: Hydrograph of Tappal observation well.

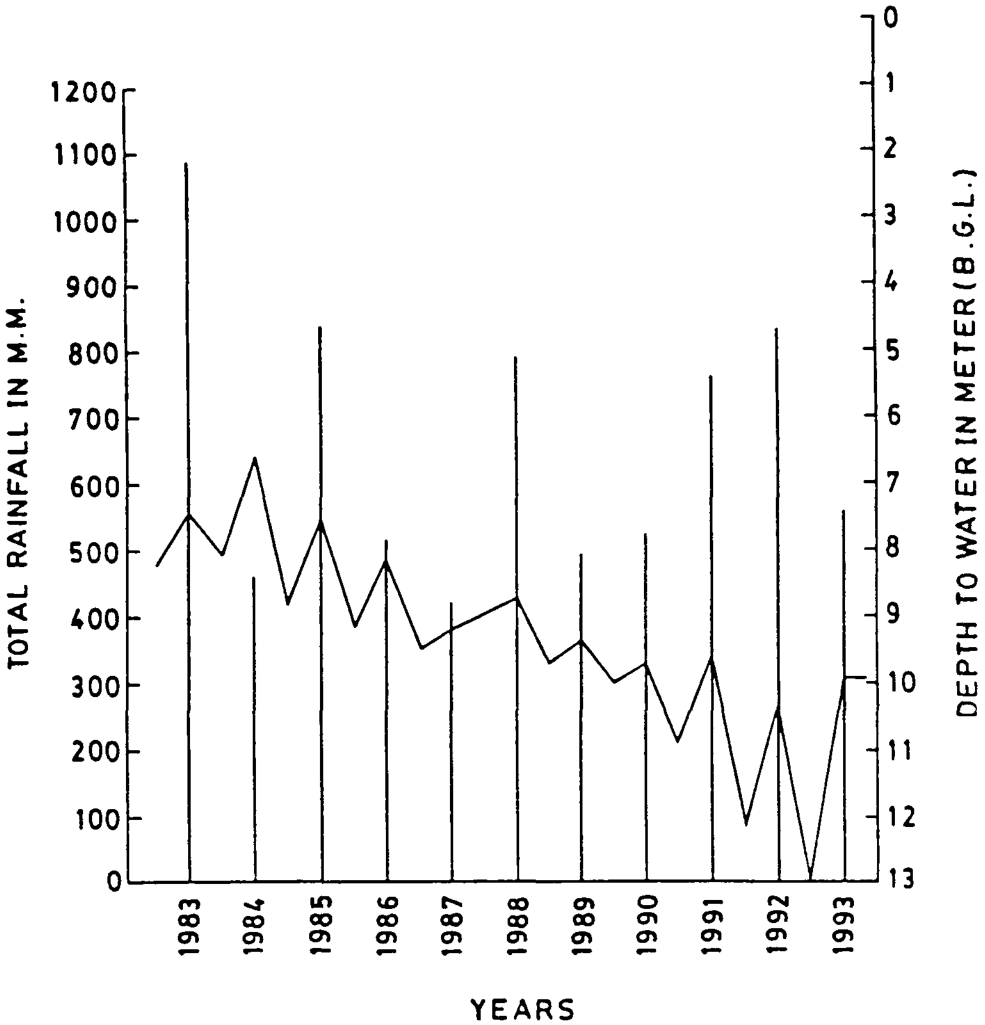


Fig. 4.15c: Hydrograph of Pisawan observation well.

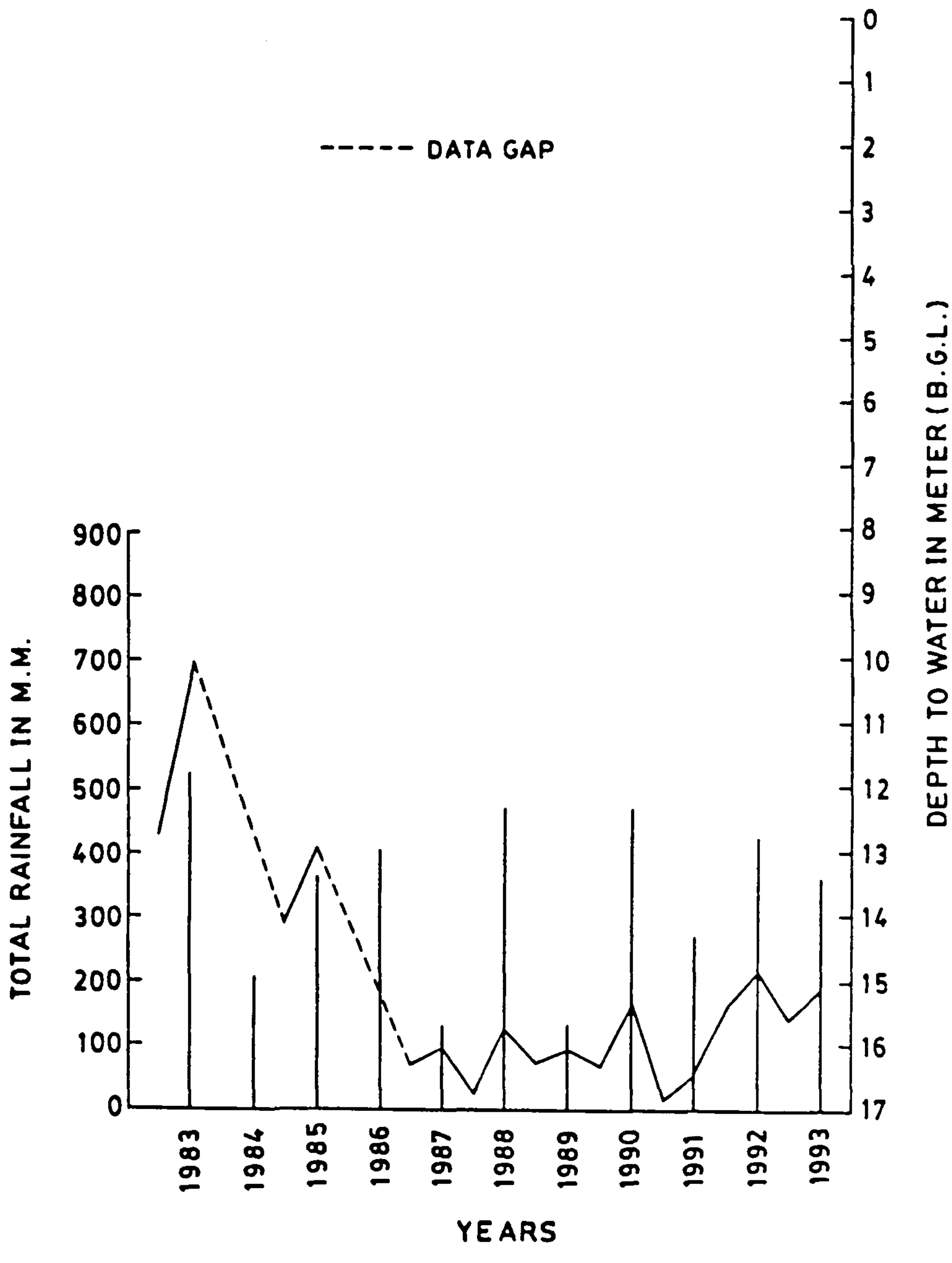


Fig. 4.15d: Hydrograph of Nojhil observation well.

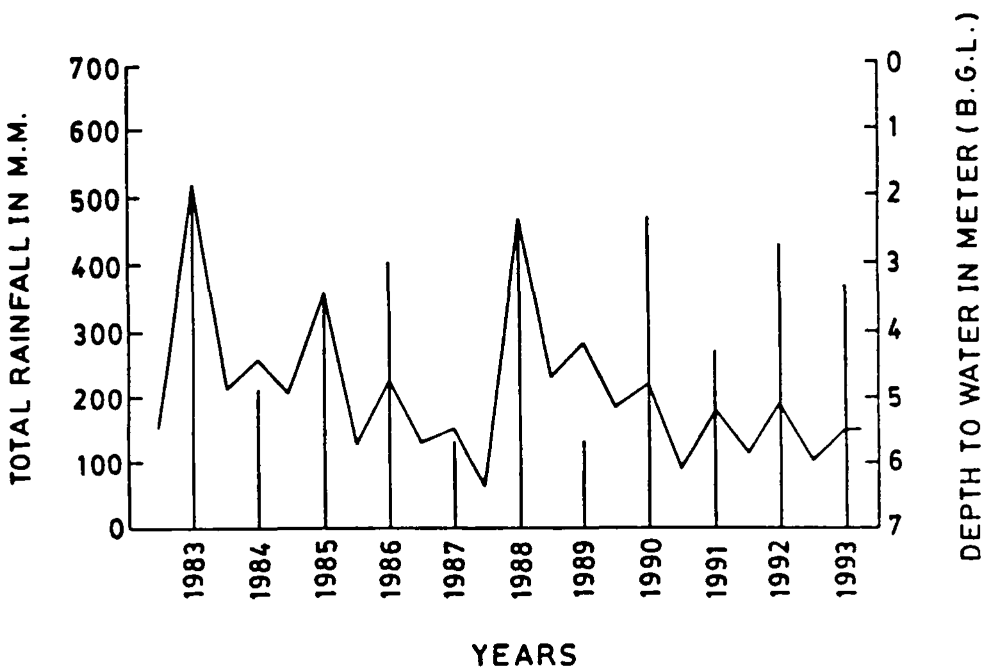


Fig. 4.15e: Hydrograph of Chinpari observation well.

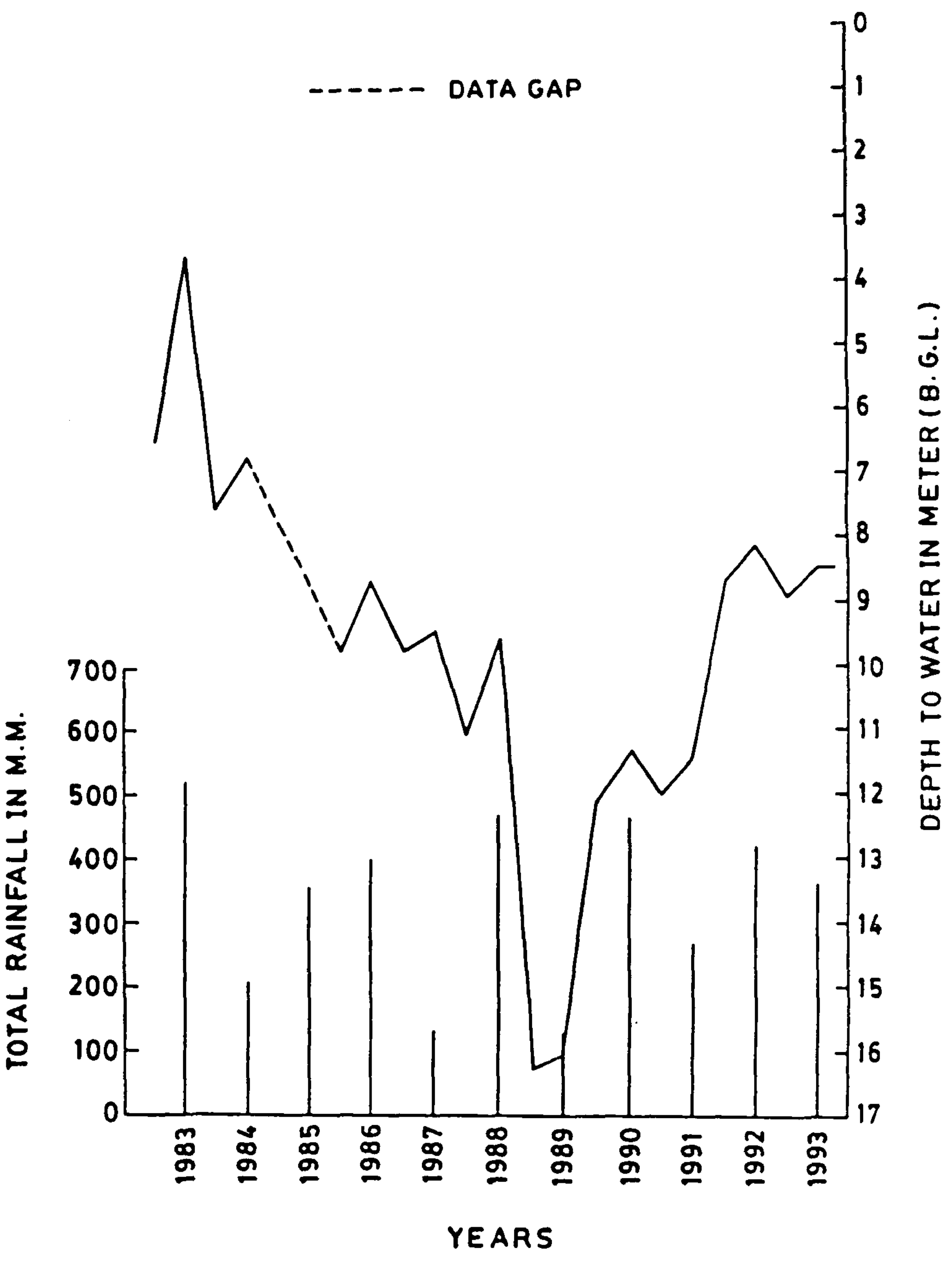


Fig. 4.15f: Hydrograph of Bajna observation well.

4.7 HYDROGRAPHS:

In order to study the groundwater behaviour with respect to time and space, and their dependence on natural phenomenon, the water levels of key observation wells were used to prepare the hydrographs of the well with respect to rainfall for the period of 1983 to 1993 (Fig. 4.15a to 4.15f). A perusal of the hydrographs indicates that water level variation is cyclic and sinuosoidal as a function of time and space. It is observed that water level starts rising by the last week of June and attains shallowest level in November. From November & December there is slow decline in water level but from January onwards the decline is very sharp.

In the view of above discussion, it is inferred that the rising and declining trends of the water level with respect to time and spece are attributed to input of groundwater namely rainfall and the seepage from canal.

Further, a critical study of the long range trend of water levels with respect to rainfall indicates the response of water levels to rainfall and drought is reasonably quick and prominent. the ascent of level is also greatly affected by the intensity and distribution of rainfall.

4.8 GRAIN SIZE ANALYSIS OF THE AQUIFER MATERIALS:

The economic development and the utilisation of groundwater resources require an understanding the factors that govern the hydraulic transmission of the groundwater through an aquifer. One of the important quantitative measures of such transmission is the permeability, which depends both upon the physical properties of flowing water and the characteristics of the transmitting medium. In many natural occurrences the physical properties of flowing water, i.e. viscosity and specific weight are practically constant so the permeability may be considered to be a function of the properties of medium alone (Masch, 1966). Such medium properties include the particle size, shape, structure, degree of compaction and grain size distribution.

The most common method of measuring particle size is sieving. The process of analysing sediments for the range sizes is called mechanical analysis. The purpose of mechanical analysis is to obtain graphic or numerical data about particle size in a sediment. Size analysis has been used in determining if a sand will contain water.

Many earlier workers attempted to relate properties of aquifer materials to the transmitting capabilities of an aquifer. Krumbien and Monk (1952) studied the effect of both particle size and sorting in artificially mixed sand and expressed their results in following semiempirical equation.

$$K = 760\ d^2\ e^{-1.\frac{36}{\sigma}}$$

where K is permeability in darcys

d = geometric mean diameter

e = dimensionless constant 2.0718

σ = the log standard deviation of size distribution which is dimensionless and 760 is a constant for the conversion of permeability units to Darcy.

A correlation between the laboratory permeability values and median grain size was developed by Bedinger (1961). He found that straight line relation existed between the logarithm of the permeability and the median grain size diameter. The results of this work revealed that the permeability expressed in gal/ft^2/day ranged from 9000 for very coarse sands to about 10 for very fine sands. Johnson (1963) has done experimental work similar to Bedinger, his results also were found in very close with those of Bedinger (1961). Kozney (1953) has studied the relationship between permeability and the pore size distribution which is governed at least partially by the grain size distribution. Preuss and Todd (1963) attempted to relate the specific yield to several physical properties of sedimentary samples including representative grain size diameter and a uniformity coefficient they found that d_{50} or median size was best studied as a measure of representative grain diameter. The uniformity coefficient used to describe the sample was defined as follows.

$$U = d_{60}/d_{10}$$

The results indicate maximum value of specific yield occured for d_{50} between 0.4 to 0.5 mm and the specific yield decreased for the values of d_{50} outside this range. they also concluded that in general specific yield decreases as the magnitude of uniformity coefficient increases. Cohen (1963) found the same results as those of Preuss and Todd. Masch, (1966) concluded that the permeability value increases with increasing value of the M.d_{50} diameter.

Uma et al., (1989) has given a new statistical grain size method for evaluating the hydraulic conductivity of sandy aquifers as follows.

$$K = Ad_{10}2$$

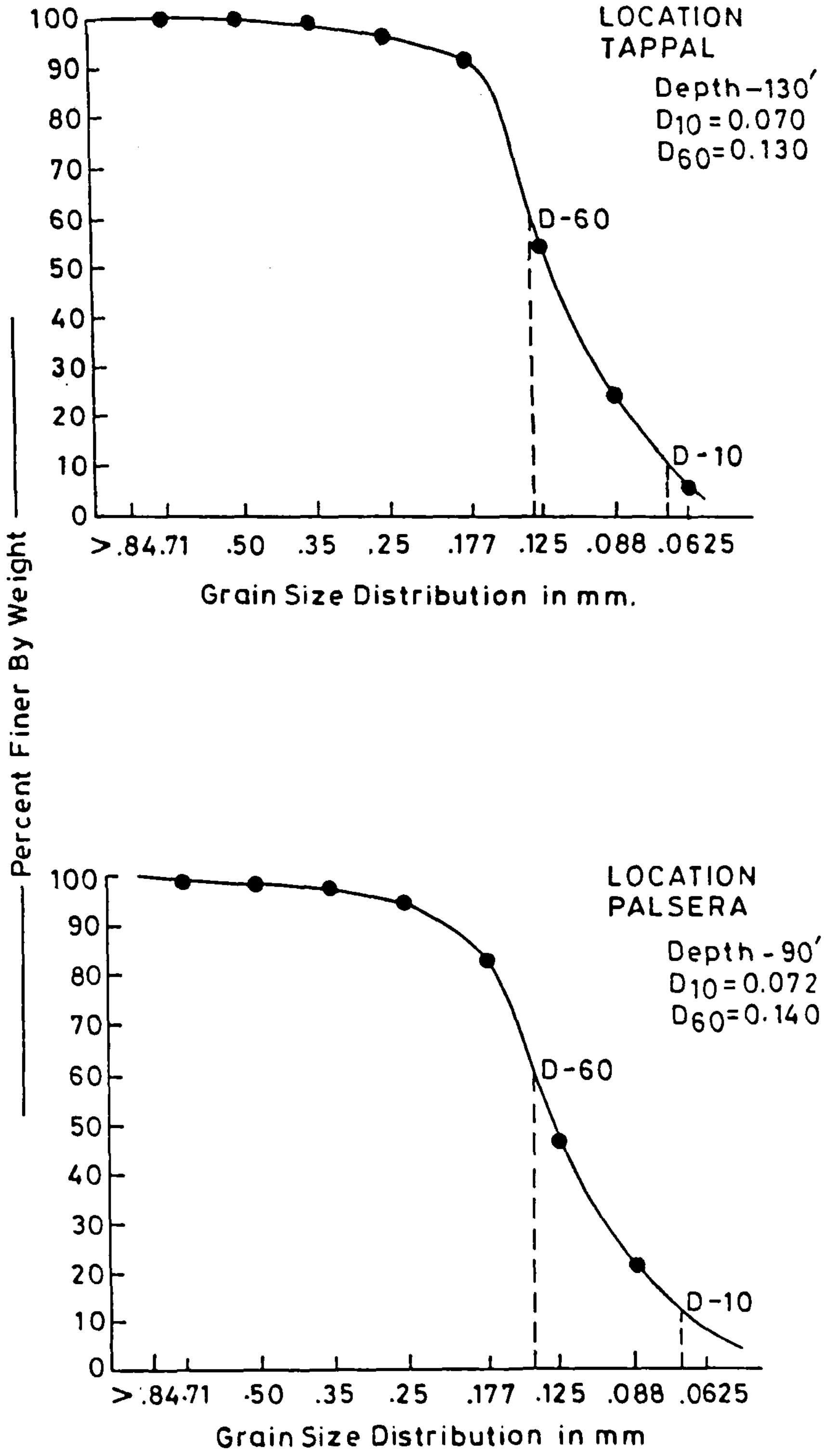


Fig. 4.16: Grading curves of Aquifer sample.

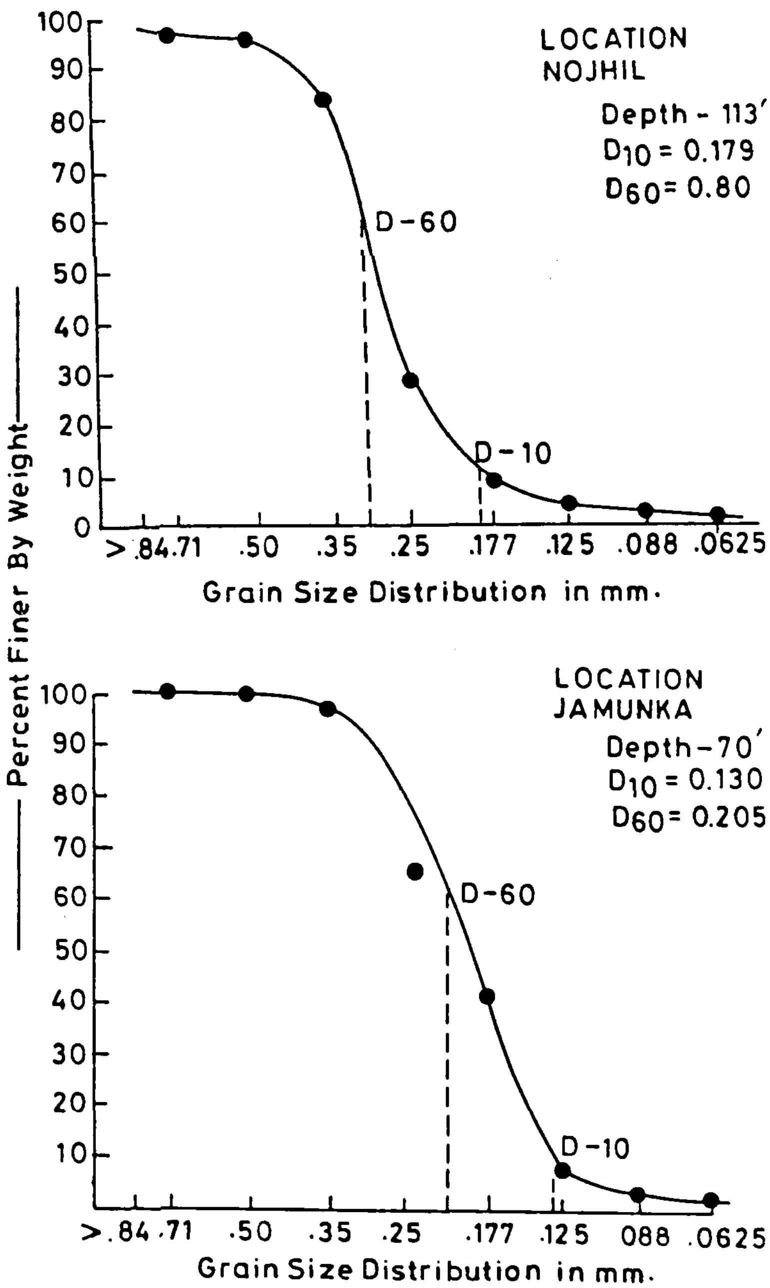


Fig.4.16: Grading curves of Aquifer sample.

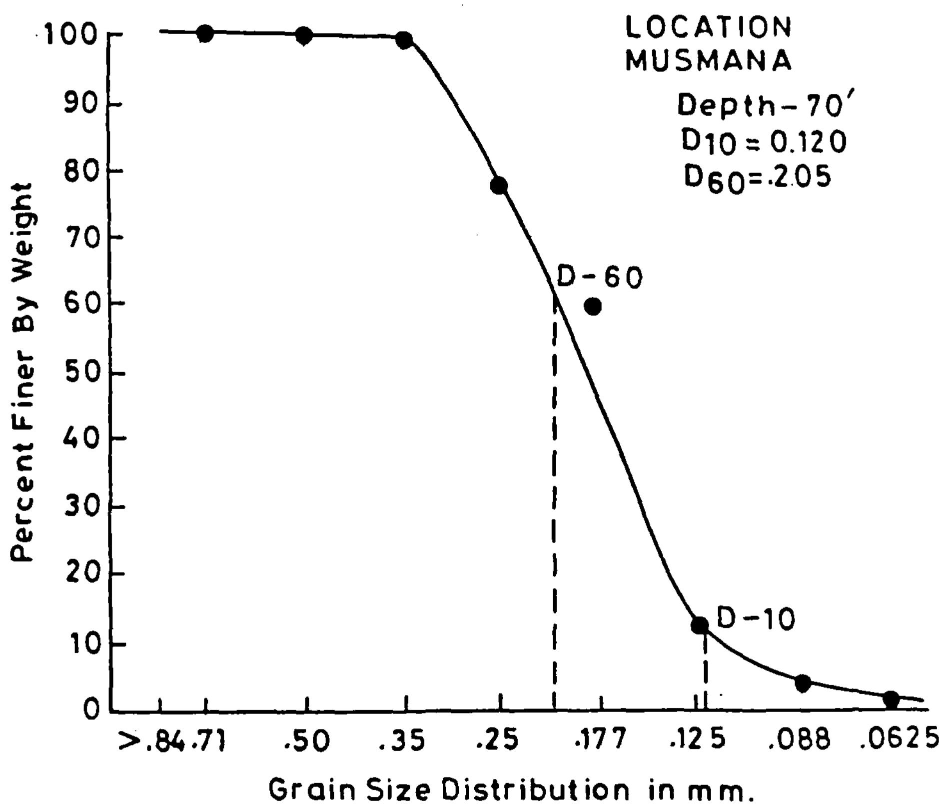


Fig. 4.16b: Grading curves of aquifer sample.

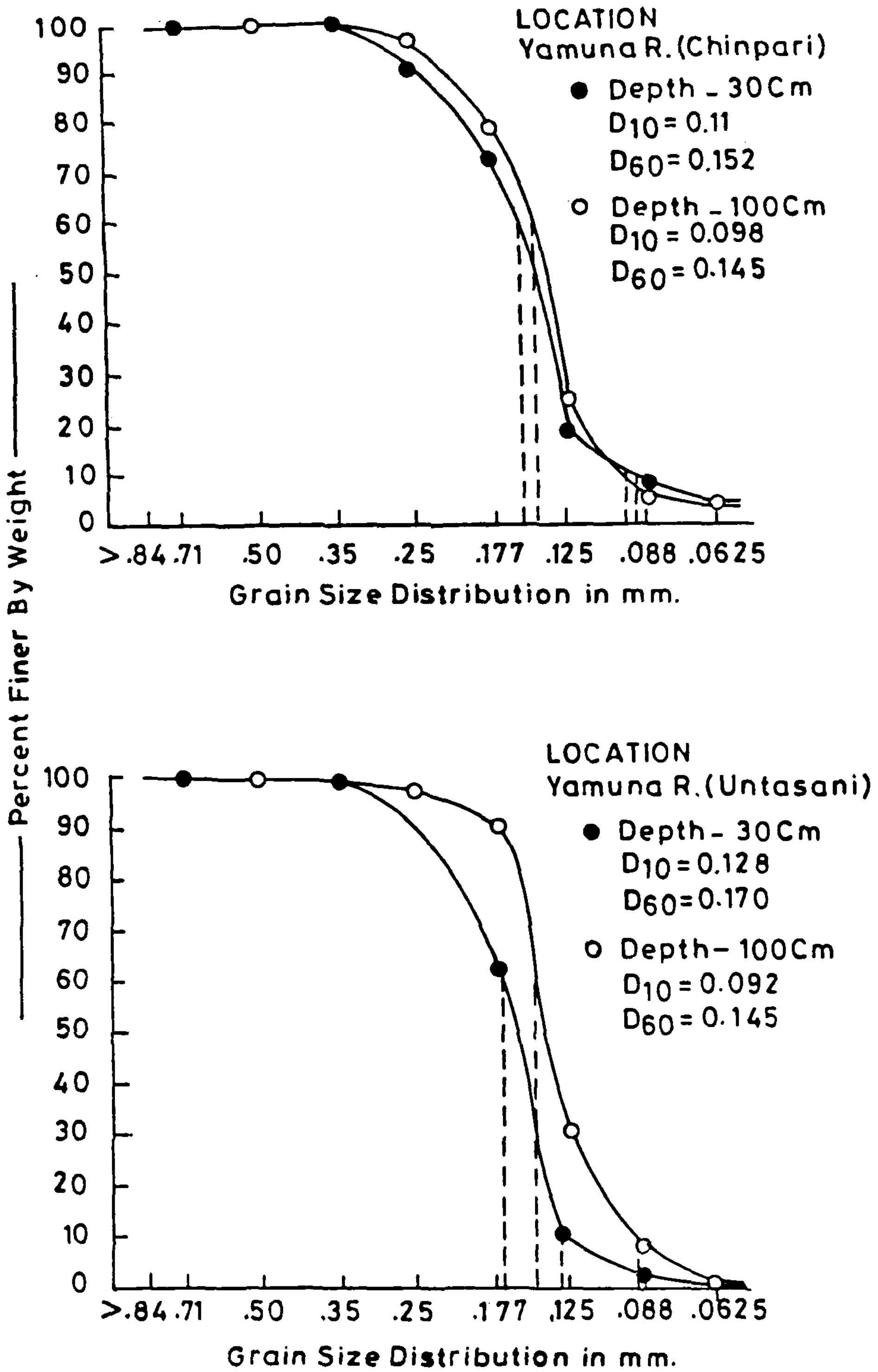


Fig.4.17a:Grading curves of sand sample of Yamuna river.

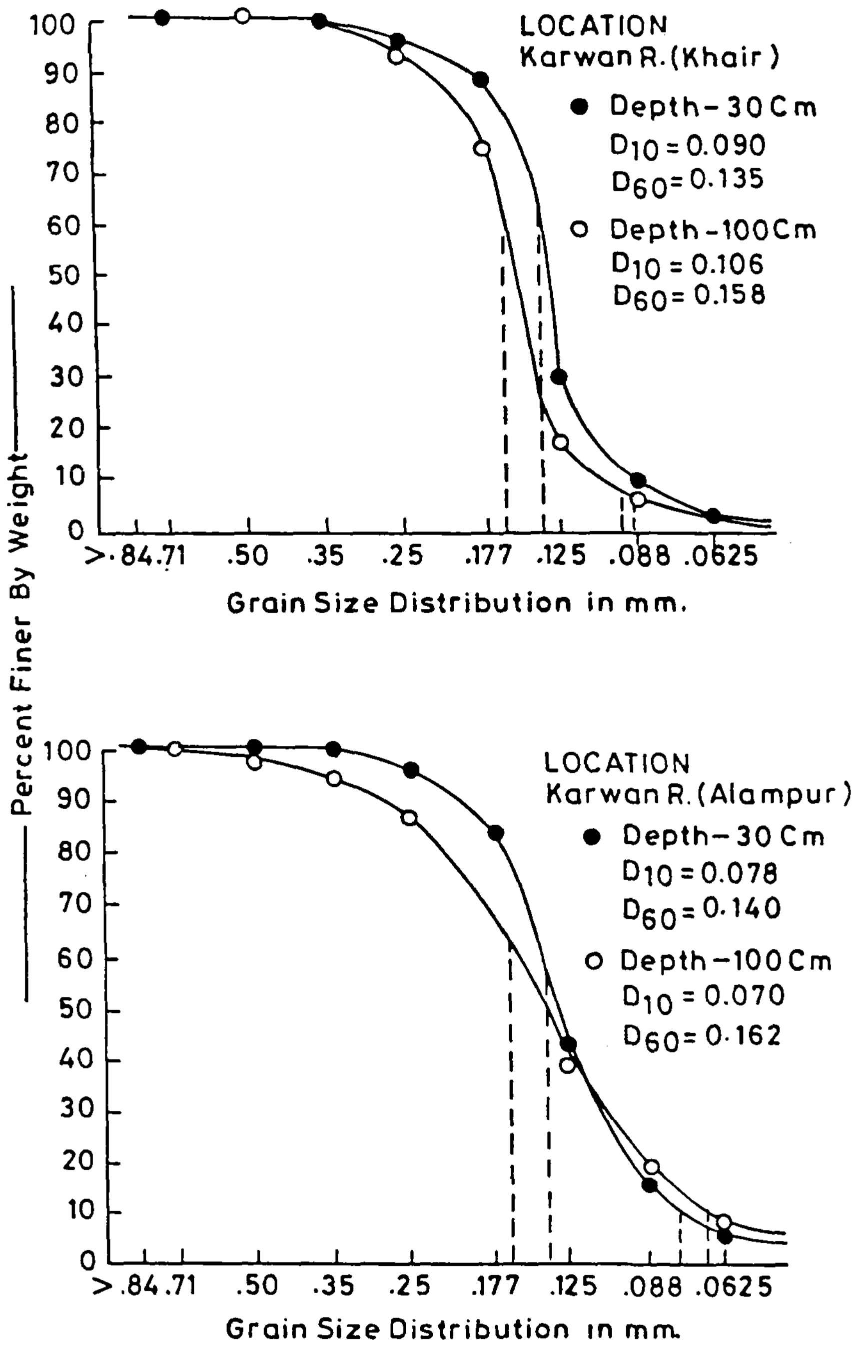


Fig.4.17b:Grading curves of sand sample of Karwan river.

Where,

K = Hydraulic conductivity

A = Constant

d_{10} = Effective grain size

where the value of A is established as 6 for sandy aquifer.

In the present investigation, aquifer materials were collected from the available drilling sites and sand samples have also been collected from the Yamuna and Karwan river beds through trenching and two samples were collected at the 30 cm and 100 cm depth trench. These samples were mechanically analysed.

The equipment required for sieve analysis includes a small hot plate for drying the samples, a set of standard testing sieves and accurate physical balance for weighing the aquifer materials. A representative sample 150-400 gms was taken in laboratory by coning and quatering. Oven dried and exact weight poured into the top sieve and covered with lid. The whole nest was shaken through shaker for about 15 minutes and material retained in each sieve was accurately weighed and data obtained were statistically analysed (Appendices - V, VI-A & VI-B). Percentage of material passing through each sieve gave a point on grading curve. The grading curve (Fig. 4.16a & 4.17a&b) was plotted on a semi-log paper to determine the following parameters.

4.8.1 Effective size:

The term effective size was developed by Allen Hazen (1892) in his studies of filter sands. He defined it as a particle size where 10% of sand is finer and 90% coarser. It is believed that d_{10} is the most important parameter among those governing the permeability properties of a medium (Marsily, 1986).

4.8.2 Uniformity coefficient (Cu):

Cu is average slope of the grading curve between 10% and 60% size and is given by

$$Cu = \frac{D_{60}}{D_{10}}$$

It gives an idea of grading of particle size distribution in material. Lower values (Cu<2) indicate more uniform material or poor grading and higher values indicate well graded material (Raghunath, 1987).

4.8.3 Hydraulic Conductivity (K):

Hydraulic conductivity was determined by using formula given by Uma et al. (1989).

$$K = Ad_{10}^2$$

where A = 6

d_{10} = effective grainsize

The results of grain size analyses show that the effective grain size of aquifer material ranges between 0.07 to 0.160 mm which shows that the sand size ranges between medium to fine. The effective grain size of the Yamuna sediment ranges between 0.092 to 0.128 mm, while the effective size of Karwan sediments ranges between 0.078 to 0.106 mm, which reveals that the Karwan sediments are finer than the Yamuna sand.

Uniformity coefficient of the aquifer material is given in (Table 4.4).

Table 4.4: Shows the values of effective size, uniformity coefficient and hydraulic conductivity (K) (Statistical grain size method)

Location	Effective grain size (d_{10})	Uniformity coefficient (Cu)	Hydraulic conductivity (K)	
			Cms^{-1}	m/day
Tappal	0.070	1.94	0.029	25.40
Palsera	0.072	1.85	0.031	26.87
Musmana	0.120	1.70	0.086	74.30
Nojhil	0.179	4.46	0.153	132.71
Jamunka	0.13	1.57	0.101	87.60

A perusal of the above table shows that uniformity coefficient ranges between 1.57 to 4.46, which reveals the value of Cu<2 except at Nojhil, where the value is 4.46, hence the porosity of the samples is high and they are uniform but at Nojhil, the sand is well graded and non-uniform. The uniformity coefficient of the Yamuna sediment (Table 4) ranged between 1.32 to 1.57. It also shows lower values for Cu i.e. < 2, which indicates that the Yamuna sediment is poorly graded and their porosity is high. The samples from Karwan river show higher values of Cu than the Yamuna sediments which ranges between 1.49 to 2.31 and indicates that the porosity of Karwan sediments is lower than the Yamuna sediments. The hydraulic conductivity in general ranges between 25.40 to 132.71 m/day of aquifer material. The hydraulic conductivity of the Yamuna sediments ranges between 43.87 to 84.93 m/day and that of the Karwan sediments varies between 25.40 to 58.24 m/day.

Table 4.5: Shows values of effective size, uniformity coefficient and hydraulic conductivity of the Yamuna and Karwan river sediments.

Location	Depth (cm)	Effective grain size (d_{10})	Uniformity coefficient (Cu)	Hydarulic conductivity (K)	
				CmS^{-1}	m/day
Yamuna River-1	30	0.11	1.38	0.072	62.20
	100	0.098	1.47	0.057	49.24
Yamuna River-2	30	0.128	1.32	0.098	84.93
	100	0.092	1.57	0.50	43.87
Karwan River-1	30	0.090	1.50	0.048	41.99
	100	0.106	1.49	0.067	58.24
Karwan River-2	30	0.078	1.78	0.360	31.53
	100	0.070	2.31	0.029	25.40

4.9 ISO-PERMEABILITY MAP:

Logan (1964) opined that if a well is pumped for such a long time that the flow is in steady state, then an approximate estimation of the order of magnitude of the transmissivity can be made using the Theims formula for a confined aquifer which can be written as:

$$T = \frac{2.3\ Q \log\ (r\ max/rw)}{2\pi S\ mw} \qquad \dots (1)$$

where,

r_w = radius of pumped well in meters

r_{max} = radius of influence in meters

S_{mw} = maximum drawdown in pumped well in meters

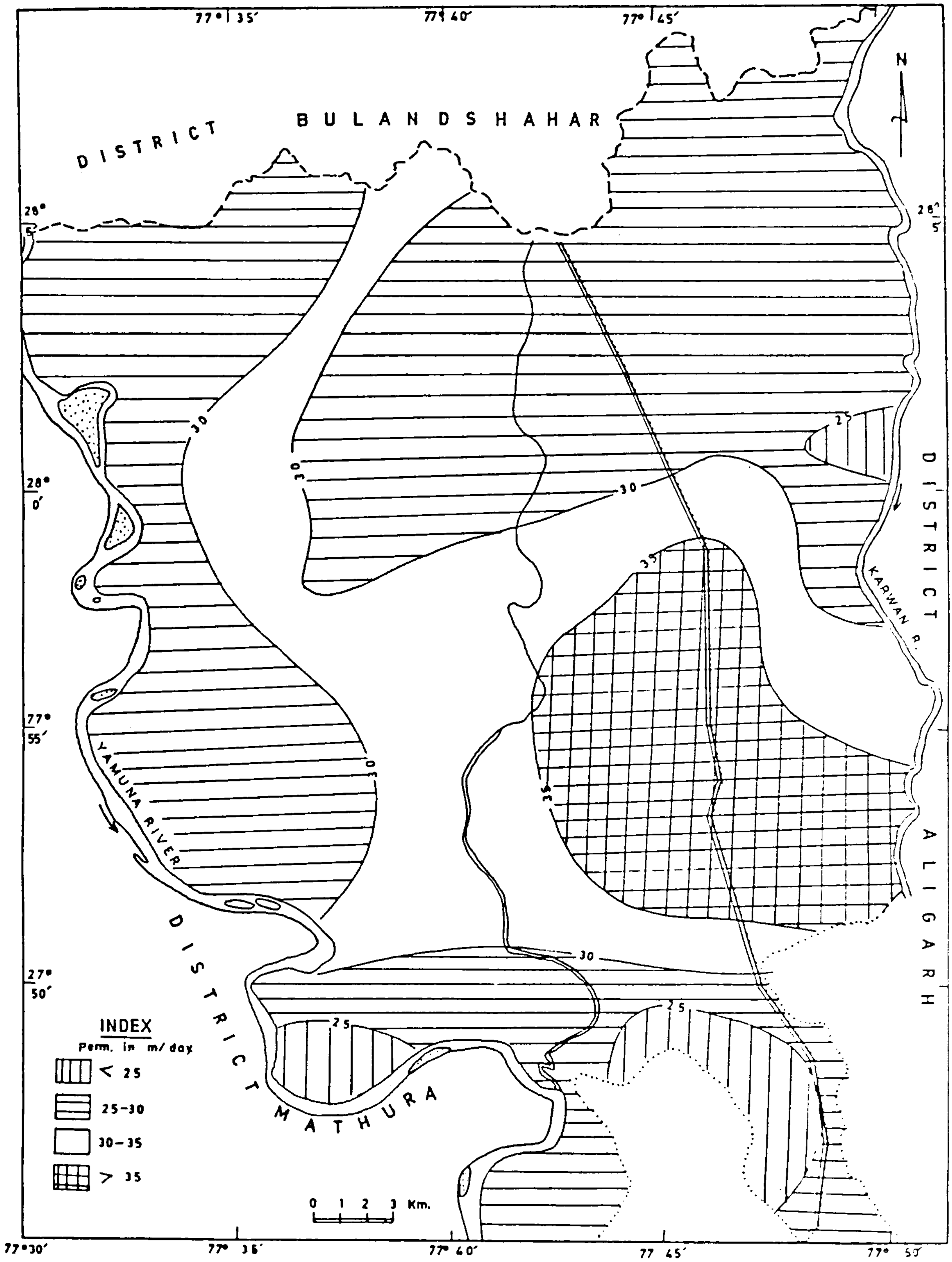


Fig. 4.18: Isopermeability map of the study area.

Logan, further stated that the accuracy of the calculation depends only on the accuracy of measurement of S_{mw} (on which well losses may have substantial influence) and on the accuracy of the ratio r_{max}/r_w. As r_{max}/r_w cannot be accurately determined generally. Logan reasoned that although the variation in r_{max} and r_w may be substantial, the variation in the logarithm of their ratio is much smaller. Hence, assuming average conditions of ratio, he gave a value of 3.33 for log ratio which may be taken as rough approximation. Substituting the value in equation (1), the Logan's formula can be written as:

$$T = \frac{1.22\ Q}{S_{mw}} \qquad \ldots (2)$$

where, S_{mw} is the maximum drawdown in a pumped well. According to Krusemann and deRider (1970) Logan's formula in above form gives erroneous results of the order of 50% or more.

However, based on Logan's formula, an isopermeability map of the area was prepared (Fig. 4.18). For the purpose, specific capacity and drawdown data of various tubewells were collected and utilised for the determination of transmissivity and permeability by Logan's formula (Appendix VII).

A perusal of the isopermeability map of the area shows that there are four isopermeability zones viz. (1) less than 25 (2) 25-30 (3) 30-45 and (4) more than 35 m/day.

The permeability ranges between 25 to 30 m/day in the area lying close to the Yamuna river, Patwahnala and at some portion of Karwan river it gradually increases towards the Mat branch canal where it ranges between 30-35 m/day with some local variations at places. In between the Karwan river and Mat canal the permeability ranges between 25 to 30 and 30 to 35 m/day in most of the area. But along the Mat canal and Patwah nala the permeability values recorded are more than 35 m/day and towards SE direction it ranges less than 25 m/day. The low values of permeability may possibly be due to the subtle variation in the grain size; sorting characteristics, and grain packing presenting microscopic inhomogeneties that control porosity and permeability, and thus fluid flow characteristics.

Because of paucity of pumping test data analysis the values of T and K determined by Logan's formula could not be compared with the pumping test data except for two places only.

In Nojhil, the value of K obtained by Logan's formula is in close agreement with the values of K determined through pumping test data analysis. But at Sopha the difference in the value is about 50%. Thus the values obtained by Logan's method give only approximate picture.

4.10 SPECIFIC CAPACITY INDEX MAP:

The specific capacity, being an index of well productivity, serves also as a parameter of yielding and transmissive capacity of an aquifer (Karanth, 1987). the yielding capacity is denoted by an yield factor (or specific capacity of the well for the unit thickness of the aquifer tapped.

$$\begin{array}{c}\text{Specific capacity Index}\\ \text{or}\\ \text{Yield factor}\end{array} = \frac{\text{Specific capacity}}{\text{Thickness of the aquifer}}$$

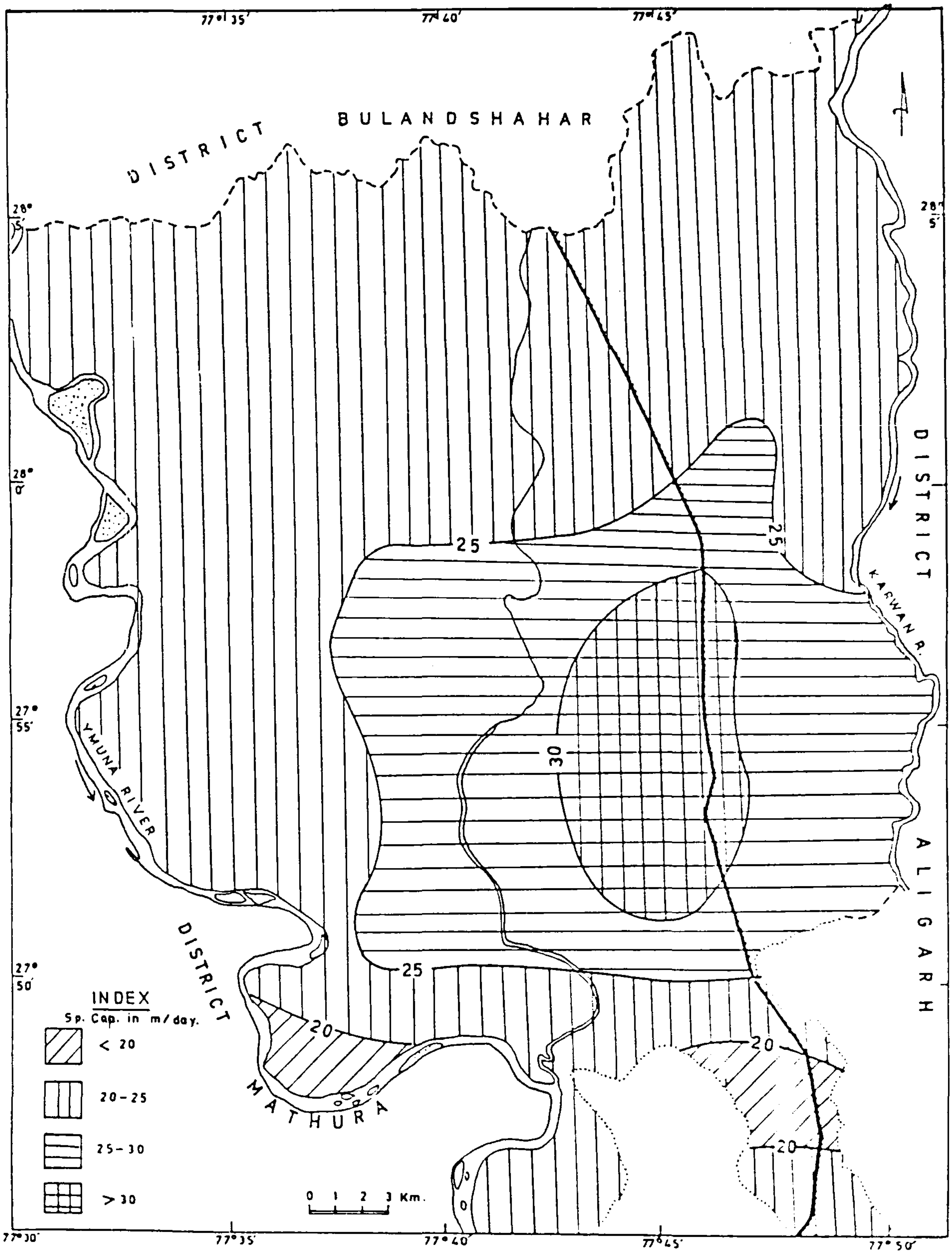


Fig. 4.19: Specific capacity index map of the area.

Based on the above formula the specific capacity index was determined from the available data of tubewells of the area, and the specific capacity index map was prepared (Appendix VII & Fig. 4.19).

A perusal of the map shows that there are following yield factor zones. (1) <20 (2) 20-25 (3) 25-30 (4) 30 m/day. The yield factor ranges between 20 to 25 m/day towards Yamuna river. The area surrounding the Khair town shows high value of specific capacity index or yield factor which ranges between 25-30 and more than 30 m/day. In the south-east portion near Mat canal the value of specific capacity index is 20 m/day. However, the average value of the specific capacity for the entire sub-basin is recorded as 24 m/day.

4.11 PUMPING TEST DATA ANALYSIS AND EVALUATION OF AQUIFER PROPERTIES

Groundwater resource development and management concern with the sustained yields of wells and aquifers, the interference between wells and well field, the interrelation between surface and groundwater and its quality. As the use of groundwater resources requires that pumping be related to water level changes with reference to time and space. The hydrogeologic properties and dimensions of aquifers, aquitards and the boundaries of aquifers are important in relating cause and effect. Hydraulic properties of aquifers and associated layers can be determined by a pumping test and data analysis. One of the fundamental aspect of groundwater resources investigation is the determination of the aquifer characteristics of permeability (K), transmissivity (T) and storage coefficient (S). These characteristics are important in determining the natural flow of water through an aquifer and its response to withdrawls. Generally, these aquifer parameters are determined on the basis of data obtained from pumping test of wells. For the proper evaluation and utilization of groundwater resources it is an essential method for reliable assessment of these parameters. Furthermore such data are also required for proper well spacing and scientific development of this valuable resource.

4.11.1 Method of Analysis:

Analysis of results of systematic observations of water level changes and other field test data yield values of aquifer characteristics. The extent and reliability of these analyses are dependent on features of the test including duration of test, number of observation wells, and method of analysis.

Various methods are available for analysis of pumping tests data of different aquifer types under different flow conditions. Each method is based on certain physical assumptions. The two types of methods are grouped as: Pumping tests under simple conditions and pumping tests under special conditions. Pumping tests under simple conditions deal with aquifers which are homogeneous, isotropic, infinite in areal extent and under fully penetrating constant discharge conditions, whereas, pumping tests under special conditions are performed on non-uniform aquifers of restricted extent under partial penetration and variable discharge conditions.

The available pumping test data of the study area are analysed by methods which were considered most appropriate to the field conditions. The method of analysis of drawdown/recovery data in different types of aquifers are outlined below.

4.11.2 Confined Aquifers:

The only solution available for radial flow problems prior to 1935 were steady-state formulae such as that of Dupuit-Theim, which frequently required a lengthy duration of pumping to satisfy the conditions governing the equation.

Theis (1935) developed the first non-steady state solution which took into account the related parameters of time factor and the removal of water from storage in the development of the cone of depression. The equation which he drived for non-steady flow in confined aquifer is expressed as:

$$S = \frac{Q}{4\pi T} \int_{u}^{\infty} \frac{e^{-u} du}{u}$$

or

$$S = \frac{Q}{4\pi T} W(u) \qquad \dots (1)$$

or

$$T = \frac{Q}{4\pi S} W(u) \qquad \dots (2)$$

where

$$U = \frac{r^2 S}{4 Tt}$$

or

$$S = \frac{4 \ Tt \ xU}{r^2} \qquad \dots (3)$$

where,

r = Distance in meters of an observation well from the pumped well in meters.

s = The drawdown in an observation well in meters

S = The storativity (dimensionless)

Q = The constant well discharge in m^3/day

T = Transmissivity in m^2/day

t = The time in days since pumping started

$W(u)$ = Well function of U

$$= -\ 0.5772 - \ln u + U - \frac{u^2}{2.21} + \frac{u^3}{3.31} - \frac{u^4}{4.41} + \ldots$$

For the use of Theis's method following assumptions and limiting conditions should be satisfied.

1. The aquifer is homogeneous, isotropic and of uniform thickness and infinite areal extent.
2. Before pumping the piezometric surface is horizontal.
3. The well is pumped at constant discharge rate.
4. The pumped well penetrates the entire thickness of aquifer, and flow is everywhere horizontal within the aquifer to the pumped well.
5. The well diameter is infinitesimal so that the storage within the well can be neglected.
6. The water removed from storage is discharged instantaneously with decline of head.
7. The aquifer is confined and flow to the well is in unsteady-state.

For calculation of aquifer parameters, Standard technique of matching field data curves ($\frac{r^2}{t}$ Vs s) with Theis's type curves W(u) Vs 1/u) choosing match point and substituting their coordinate values in the equations mentioned, are used. The values are plotted on a double logarithmic paper.

4.11.3 Jacob's Method:

Copper and Jacob (1946) suggested a simplification of Theis equation (1) which dispenses with the need for type curves by utilizing a semilogarithmic plot for those field data where $u \leqslant 0.01$, which beyond the first log cycle of time usually gives a straight line relationship.

Jacob has shown that for small value of u ($u \leqslant 0.01$), i.e. when r is small and t is large, the Eq. $s = Q/4\pi T\, W(u)$ can be simplified and expressed as:

$$s = \frac{2.30\ Q}{4\pi T} \log \frac{2.25\ Tt}{r^2 S} \qquad \ldots (4)$$

Thus a plot of drawdown(s) versus the logarithm of time (t) or distance (r) from the pumped well describes a straight line. Equation (4) can further be solved to give:

$$T = \frac{2.30\ Q}{4\pi\, \Delta s} \qquad \ldots (5)$$

$$S = \frac{2.25\ Tt_o}{r^2} \qquad \ldots (6)$$

where,

t_o = the time intercept in days corresponding to interception of straight line with zero drawdown axis, s = 0

Δs = slope of the straight line in meters.

By plotting time versus drawdown on a semi-logarithmic paper (time on log scale) a straight is fitted by discretion. The slope of straight line Δs, the drawdown difference over one log cycle of line are determined and by substituting the values of Q and Δs in equation (5) for determination of T. By substituting the values of computed T, to and r into Eq. 6 the value of S is determined.

For use of Jacob's method, the same assumptions as for the Theis's method are followed and the value of 'u' should be small ($u \leqslant 0.01$) i.e.'r'is small and 't'is large.

4.14.4 Aquifer Performance Test:

Prior to present investigation various agencies had undertaken hydrogeological investigations of the study area for different purposes. As part of present investigation efforts were made to collect aquifer parameter data for the analysis.

The Central Groundwater Board and State Groundwater Department have carried out exploratory drilling in various parts of Aligarh-Mathura districts. During investigation, short duration pump tests were conducted with or without observation wells by the hydrogeologists at the different sites. But, in the present investigated area the pump tests were conducted only at two places i.e. village Makhdumpur (Nojhil Block) and Sopha (Khair block). The details of pump test results at village Makhdumpur are summarised as below:

Method used	Flow condition	T(m^2/day)	S	K(m/day)
Theis	Unsteady state	411.0356	6.77842×10^{-2}	21.6334
Theis Recovery	Unsteady state	759.681	-	39.9832
Cooper Jacob	Unsteady state	580.120	5.178×10^{-2}	30.5320
Chow's	Unsteady state	398.4569	8.073×10^{-2}	20.9714

The pump test data of aquifer performance test conducted at village Sopha in Khair block by C.G.W.B. was collected and analysed to determine the various aquifer parameters, are computed and given as under:

Summary of Observation

1.	Name of site	:	Village Sopha
	Block & Sub-division	:	Khair
	District	:	Aligarh
2.	Longitude & latitude	:	77°45'20", 27°58'40"
3.	R.L. of ground level	:	194.73 mts.
4.	Date of test	:	29.8.82 & 30.8.82
5.	Pump started on	:	29.8.82 at 1200 hrs.
6.	Pump stopped on	:	30.8.82 at 1225 hrs
7.	Duration of pumping	:	1465 mts.
8.	Thickness of aquifer tapped	:	27 mts.
9.	Static water level in main well	:	6.88 mts.
	Static water level in observation well	:	6.87 mts
10.	Distance between main well and observation well	:	15.75 mts.
11.	Maximum drawdown:		
	Main well	:	6.30 mts.
	Obs. well	:	4.65 mts.
12.	Discharge at which test conducted	:	0.368 m^3/sec or 36.83 LPS

4.11.5 Analysis of Data:

The pumping data and recovery data recorded during test are given in appendices VIII A & VIII B.

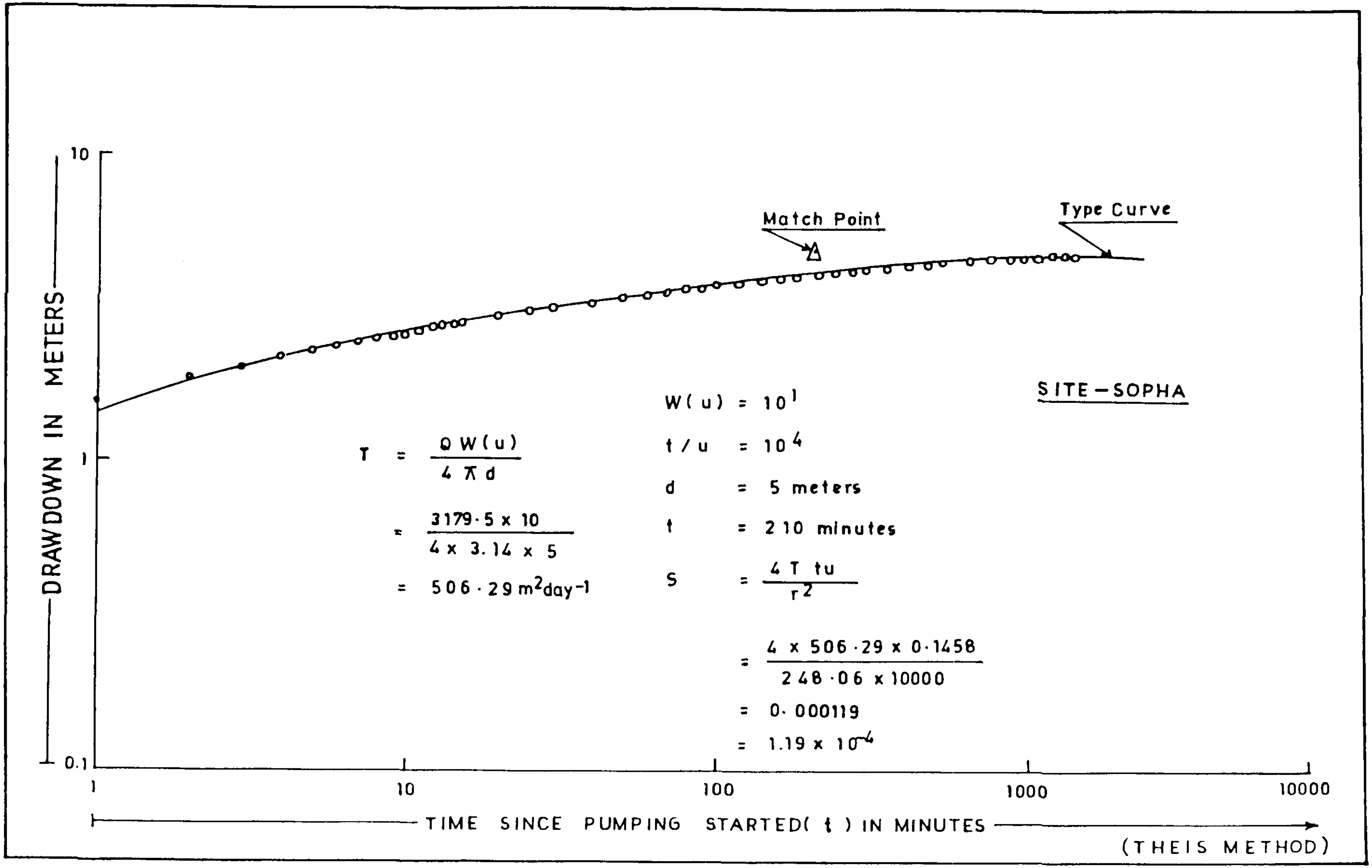


Fig. 4.20: Plot of time vs drawdown (Theis Method) observation well - village Sopha.

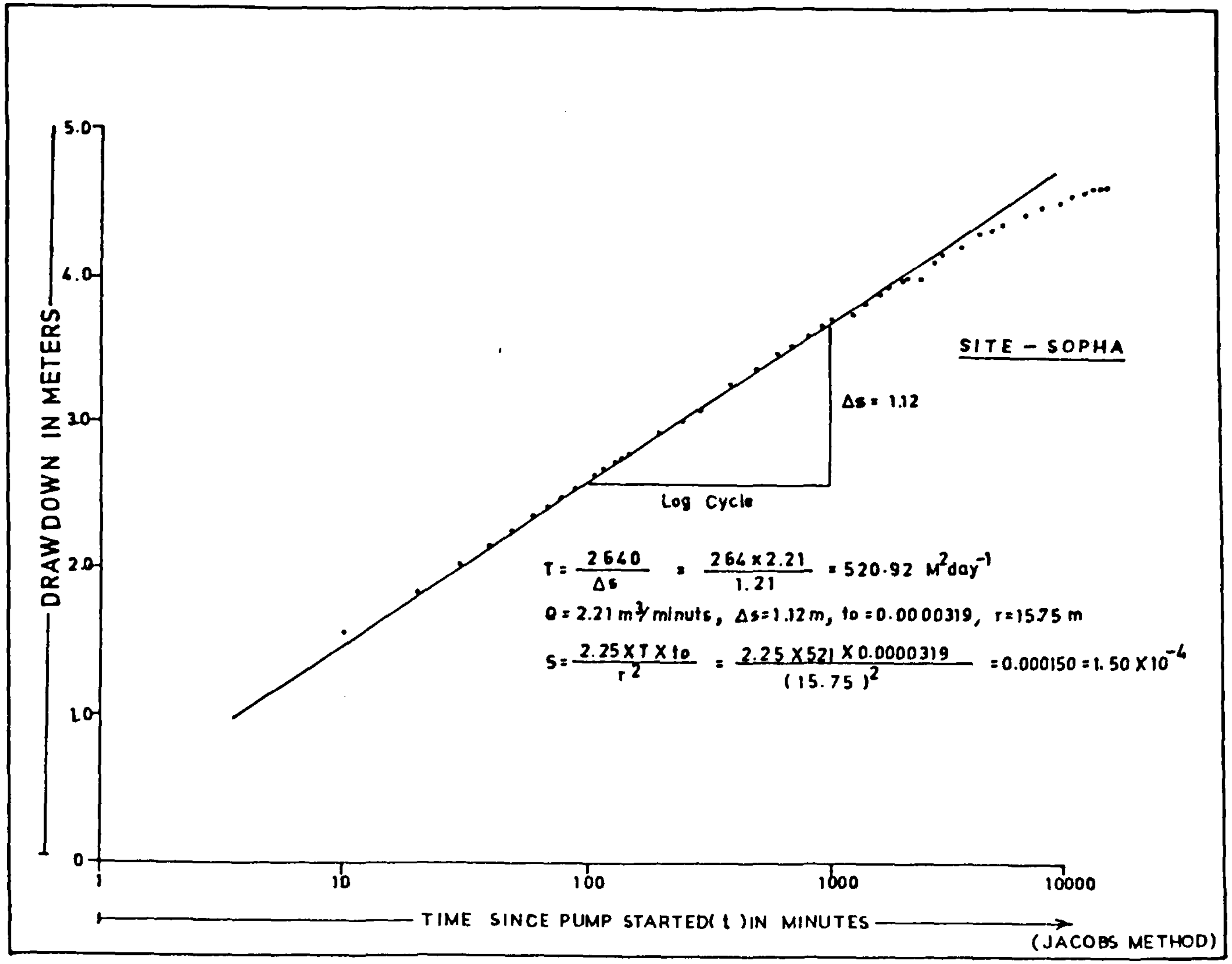


Fig. 4.21: Plot of time Vs drawdown (Jacob's Method) - observation well - village Sopha.

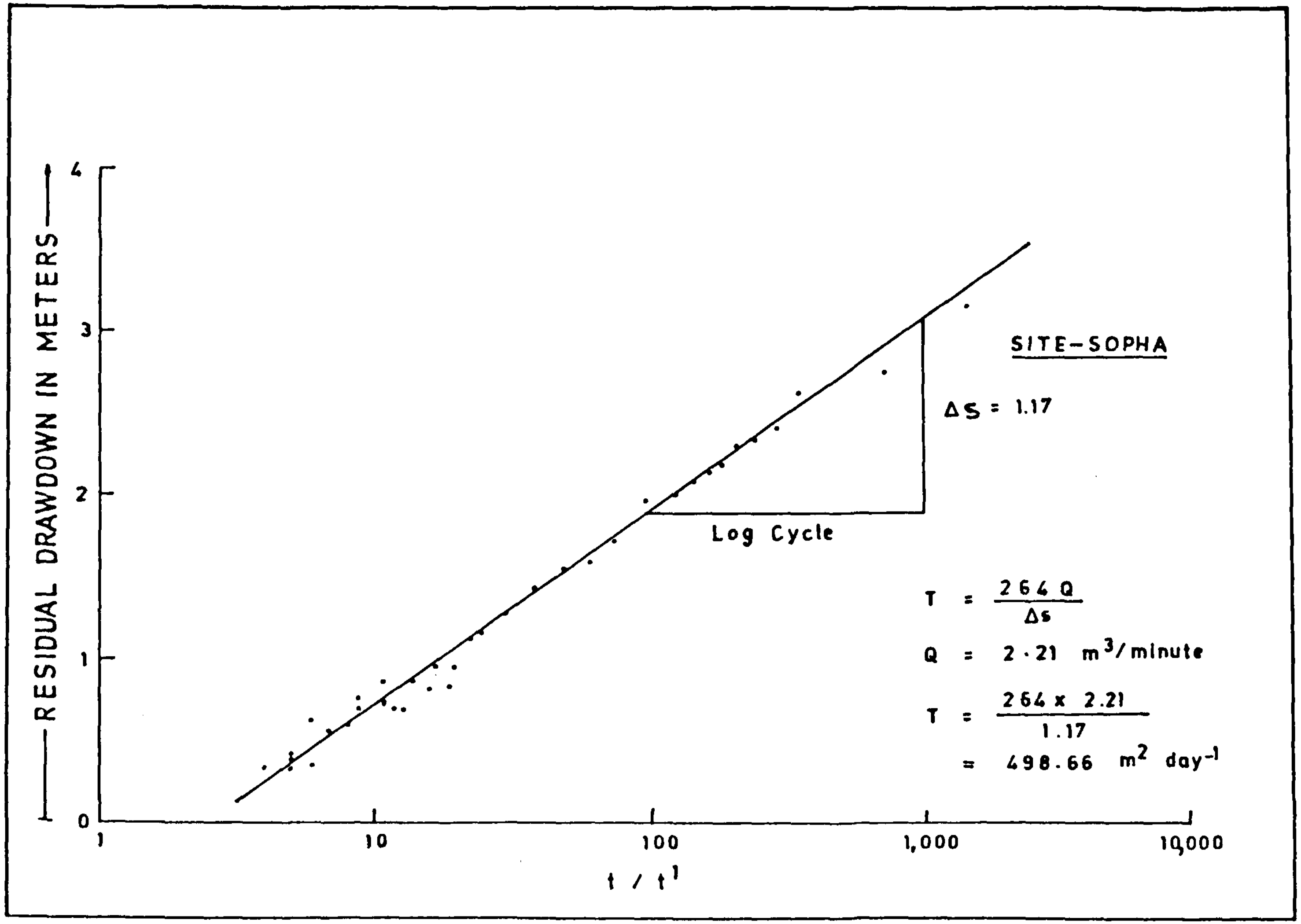


Fig. 4.22a: Plot of Residual Drawdown Vs t/t' (Recovery method), site Sopha. (Main well).

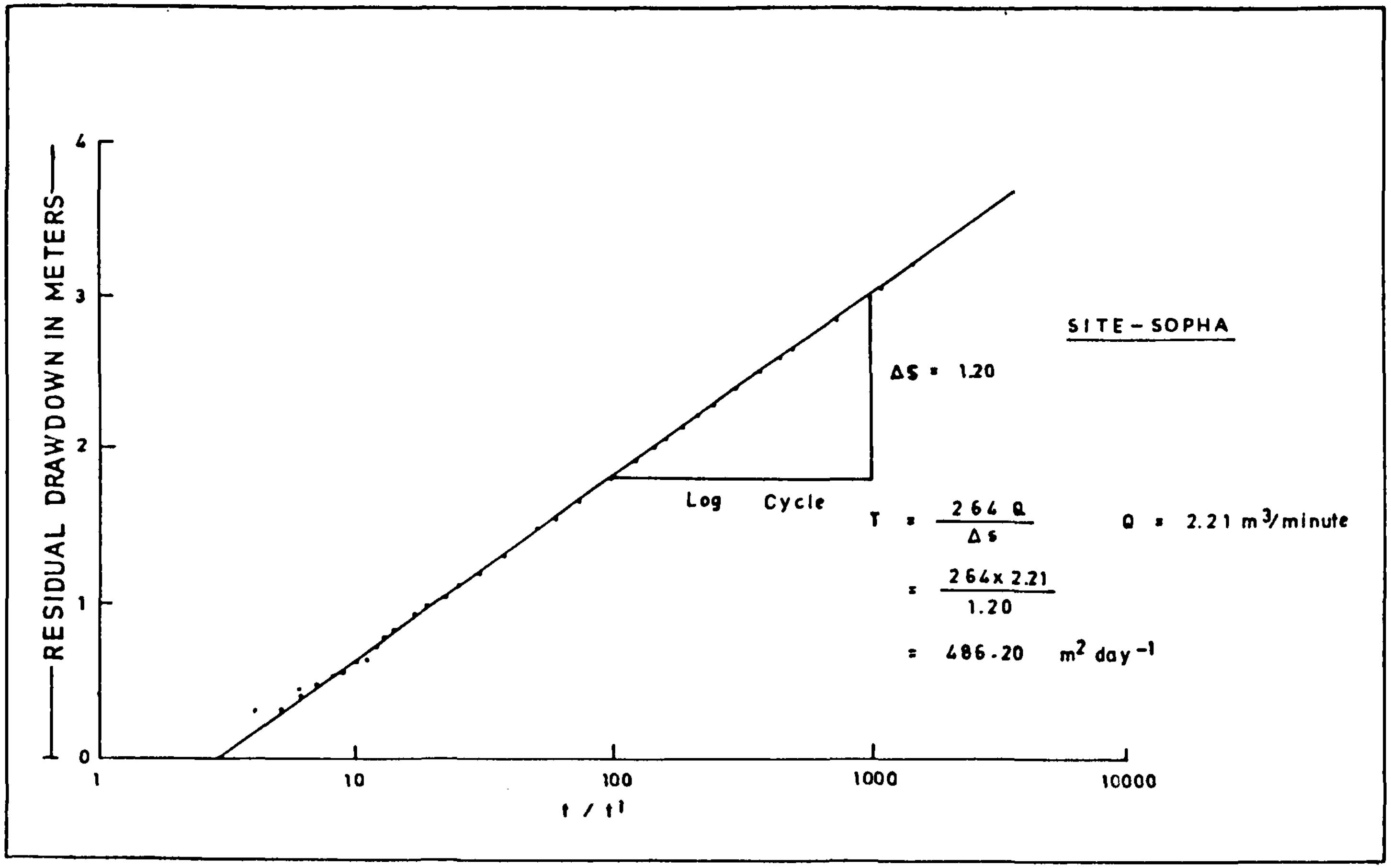


Fig. 4.22b: Plot of residual drawdown Vs t/t' (Recovery method) observation well - village Sopha.(Observation well).

Time-drawdown field data curves of observation wells resemble the typical 'time-drawdown curve' for a confined aquifer, and suggest an unsteady state flow conditions, Thies's, Jacob's and recovery methods to calculate aquifer parameters have been selectively used (Fig. 4.20, 4.21, 4.22a & 4.22b).

4.11.6 Evaluation of Results:

Aquifer-parameters evaluated by pumping test data analysis are tabulated as below:

Methods	Well data	Transmissivity (T) m^2/day	Storavity (S)
Theis method	Observation well	506.29	1.19×10^{-4}
Jacob's method	Observation well	520.92	1.50×10^{-4}
Recovery method	Main well	498.66	-
	Observation well	486.20	-

Since the results obtained by analysing the data through various methods are almost comparable, but the field curve of observation well match well with Theis type curve, hydraulic properties of the aquifer determined by this method can be taken as best approximation of aquifer parameters.

It may be concluded that tested aquifer of thickness tapped as 27 meters is confined in nature and has the following hydraulic properties:

(i)	Transmissivity (T)	=	503 m^2/day
(ii)	Storavity (S)	=	1.34×10^{-4}
(iii)	Hydraulic conductivity (K)	=	18.64 m/day

The quality of the groundwater below 85 meters depth was found doubtful and in depth from 114 to 120 meters b.g.l., the quality is very poor.

CHAPTER - V

GROUNDWATER RESOURCE ASSESSMENT

GROUNDWATER RESOURCE ASSESSMENT

To meet the food and fibre requirements adequately, India has to increase its crop production considerably and there is a need for holding strategic planning to maintain the momentum of 'Green Revolution'. Groundwater which contributes a considerable part of irrigation potential created in the country is therefore of vital importance. Groundwater development activity has been increased considerably during the last two decades. This development has taken place indiscriminately without regard to the annual replenishment.

To provide maximum development of groundwater resources for beneficial use requires thinking in terms of entire groundwater basin. By visialization a basin as a large natural underground reservoir, it is clear that utilization of groundwater by one land owner affect the water supply of other land owners. A river basin forms a closed system of surface and groundwater. Therefore, it is essential that various aspects of water in transit through a basin are quantitatively evaluated and definite recommendations in regard to its development are made. The ultimate goal of quantitative hydrologic measurements is to determine addition of water to the groundwater reservoir of the area under investigation from all sources (groundwater increment) and discharge from the groundwater body (groundwater decrement).

In the state of Uttar Pradesh, there is a large scale water logging in all the canal command areas whereas in the tubewell irrigated areas water levels show a declining trend due to over-development of the shallow aquifers (Chaturvedi, 1976). Moreover, with the advent of high yielding varieties of wheat and paddy which need assured and timely irrigation, has accelerated the pace of groundwater development through large number of shallow farmer's tubewells in rural areas. Under the circumstances, the situation necessitates as far as possible, the precise evaluation of groundwater resources of a basin or part of it.

In the Yamuna-Karwan sub-basin, the area which lies adjacent to the canals is water logged because of the canal seepage, whereas in the rest of the area, the groundwater levels show a very well marked declining trends since past few decades. The declining water table can be attributed to the large scale groundwater development through clusters of shallow and deep tubewells.

The study area thus represents extreme situation of water logging on the one hand and the declining trend on the other. However, the scenario necessitates the evaluation of total groundwater recharge and discharge in order to quantify the total water resources of the Yamuna-Karwan sub-basin in parts of Aligarh and Mathura districts of the Central Ganga plain.

Quantification of water resources of any basin involves the application of principle of conservation of mass, to account for quantitative changes occuring in various components of hydrologic cycle as applied to the basin. The quantitative changes may be expressed as water balance equation in which the inflow-outflow and changes in storage in a period of time are represented by individual components.

The recharge and draft effecting the groundwater reservoir have been worked out as:

$$I - O = \pm \Delta S$$

where,

I = Inflow

O = Outflow

Δ S = Change in storage

It is therefore, imperative to identify the various recharge and discharge, components of groundwater regime and their effect on its variation with time.

5.1 GROUNDWATER RECHARGE:

Evaluation of groundwater recharge parameter form an important aspect of groundwater evaluation. It involves hydrometeriological and hydrological processes, taking place on the surface and also involves sub-surface lithological characteristics (Baweja & Karanth, 1980).

Various estimations of groundwater recharge in the country have been made (Rao, 1965; Raghava Rao et al., 1964; Irrigation Commission, 1972 and Pathak, 1982), while the earlier estimations were based on adhoc norms not supported by the filed tests. A large amount of data generated in recent years as a result of the extensive multi-disciplinary project studies undertaken by both the Central Groundwater Board (C.G.W.B.) and State Groundwater Department have made realistic appraisals rather easier.

The major source of groundwater recharge in the area are:

1. Recharge through rainfall
2. Recharge through canal seepage
3. Recharge through irrigation return flow

There are various methods to estimate groundwater recharge, such as, water-table fluctuation method and rainfall-recharge method Adhoc norms etc.

In view of the prevailing irrigation pattern in the area, the quantum of seepage to the aquifers play a very significant role. Hence, the estimation by seasonal fluctuation and specific yield have been adopted for the present study.

5.2 GROUNDWATER DRAFT:

The discharge of groundwater in the area mainly takes place through various groundwater structures such as dugwells, pumping sets, shallow farmer's tubewells and state tubewells. In the present study, only the gross annual draft from the existing groundwater structures is taken into account for calculating the groundwater discharge.

The unit drafts for these groundwater structures have been estimated by the State Groundwater Department, Uttar Pradesh, for this area have been utilized in the evaluation of the groundwater draft.

5.3 STAGE OF GROUNDWATER DEVELOPMENT:

In order to determine the stage of groundwater development in the study area, as per the NABARD's

(National Bank for Agriculture and Rural Development) norms have been taken into account, which are as follows:

State of Development	Category
Upto 65%	White or safe
65 - 85%	Grey or semi-critical
Morethan 85%	Dark or critical

The position of recharge, draft, groundwater balance and its stage of development has been computed block-wise in the study area and the stage of groundwater development of the entire investigated Yamuna-Karwan sub-basin is assessed according to the norms laid down by National Bank for Agriculture and Rural Development (NABARD) and Groundwater Estimation Committee (1984) are as follows:

ANNUAL RECHARGE:

(i) Monsoon recharge (ham)

= Geographical Area x Specific yield x W.T. Fluctuation) + Gross Kharif Draft - (Monsoon Canal Seepage + Monsoon Recharge from Surface water Irrigation + Monsoon Recharge from Groundwater Irrigation) x

$$\frac{\text{(Normal monsoon rainfall)}}{\text{(Average monsoon rainfall)}} + \text{Monsoon recharge}$$

from surface irrigation + Monsoon recharge from canal seepage.

(ii) Non-monsoon rainfall recharge (ham)

= Geographical area x Non-monsoon rainfall x Infiltration factor.

(iii) Recharge from surfacewater sources

(a) Recharge from canals:

Total seepage (ham) = Length of canal x Average wetted parameter x Running days x Seepage factor .

(b) Recharge from irrigation water return flow:

Total yearly cropwise return seepage (ham) = Average irrigated area (ha) x Average wetted depth (m) x Seepage factor %

(c) Recharge from tanks & pods:

Yearly recharge (ham) = Water spread area ha x Seepage factor (cm/year)

(iv) Gross annual recharge

= Monsoon recharge + Non-monsoon recharge

(v) Net annual recoverable recharge

= 85% of the Gross Annual recharge

GROUNDWATER DRAFT:

(i) Draft by dugwells

Yearly draft (ham) = No. of wells x Unit draft/year

(ii) Draft by shallow tubewells/pump sets

Yearly draft (ham) = No. of tubewells x Unit draft/ year

(iii) Draft by deeptubewells

Yearly draft (ham) = No. of deep tubewells x Unit draft/year

(A) Gross annual draft:

Total yearly draft (ham) = Monsoon draft + Non-monsoon draft

(B) Net annual draft (ham) = 70% of Gross Annual Draft

GROUNDWATER BALANCE:

$$I - O = \pm \Delta S$$

Net annual recharge - Net annual draft
= Groundwater balance (ham)

STAGE OF GROUNDWATER DEVELOPMENT:

(i) Present stage of groundwater development (%)

$$= \frac{\text{Net annual draft}}{\text{Net annual recharge}} \times 100$$

(ii) Stage of groundwater development at 5 years (%)

= Present stage + 5 x yearly rate (%)

5.4 GROUNDWATER ASSESSMENT OF KHAIR BLOCK:

ANNUAL RECHARGE:

(i) Monsoon recharge (ham):

1. Year of observation = 1992 & 1993
2. Total geographical area = 32196.33 hactares

3. Water table fluctuation = 1.03 m
4. Adopted specific yield = 17%
5. IMD Normal yearly rainfall = 616.80 mm
6. IMD Normal monsoon rainfall = 552.40 mm
7. IMD Non-monsoon rainfall = 38.80
8. Average monsoon rainfall = 664 mm
9. Gross Kharifdraft = 2002.50 ha.m.
10. Infiltration factor = 25%

Monsoon Recharge = (32196.33 x 0.17 x 1.03) + 2002.50 - (439.84 + 2285.44 + 563.56) x 552.40/664.0 + 2285.44 + 439.84 = 6345.18 ham.

(ii) Non-monsoon rainfall recharge = 32195.33x0.0388x0.25 = 312.30 ham.

(iii) Recharge from surface water sources:

(a) Recharge from canals
Applied seepage factor = 15 ham/day/10^6sq.m of wetted area of canal

1. Main Canal:

Average wetted parameter = 15.27 m,
length = 18000m. Running days (Monsoon = 70 days, Non-monsoon = 200 days)
Non-monsoon seepage = $18000 x 15.27 x 200 x 15 x 10^{-6}$
= 824.58 ham
Monsoon seepage = $18000 x 15.27 x 70 x 15 x 10^{-6}$
= 288.60 ham
Yearly seepage = 1113.18 ham

2. Distributaries:

Average wetted parameter = 9.16, length=29500m
Running days (Non-monsoon = 100 days,
monsoon = 30 days)

Non-monsoon seepage = $29500 \times 9.16 \times 100 \times 15 \times 10^{-6}$
= 405.33 ham

Monsoon seepage = $29500 \times 9.16 \times 30 \times 15 \times 10^{-6}$=121.60ham

Yearly seepage = 526.93 ham

3. Minors:

Average wetted parameter = 2.44, length=27000m

Running days (Non-monsoon = 100 days,

Monsoon = 30 days)

Non-monsoon seepage = $27000 \times 2.44 \times 100 \times 15 \times 10^{-6}$
= 98.82 ham

Monsoon seepage = $27000 \times 2.44 \times 30 \times 15 \times 10^{-6}$=29.64 ham

Yearly seepage = 128.46 ham

4. Total Non-monsoon canal seepage = 1328.73 ham

Total monsoon canal seepage = 439.84 ham

Total annual canal seepage = 1328.73+439.84
= 1768.57 ham

(b) Recharge from irrigation water return flow:

1. Kharif crop:

Seepage factor = 40%, Average wetted depth = 0.40m,

Average irrigated area = 13627 ha.

Monsoon return flow = 13627 x 0.40 x 0.40=2180.32 ham

2. Rabi crop:

Seepage factor 30%, Average wetted depth 0.40 m

Average irrigated area = 24501 ha

Non-monsoon return flow = 24501x0.30 x 0.40
= 2940.12 ham

3. Sugarcane - I:

Seepage factor = 30%, Average wetted depth = 0.15 m,

Average irrigated area = 2336 ha

Monsoon return flow = 2336x0.15x0.30 = 105.12 ham.

Sugarcane-II

Average wetted depth = 1.00m

Non-monsoon return flow = 2336x1.00 x0.30 =700.80ham

Total yearly return seepage

= Non-monsoon seepage + Monsoon seepage

= 3640.92 + 2285.44 = 5926.36 ham

(c) Recharge from Tank & Ponds:

No. of Tanks = 66, water spread area = 73.12 ha

Seepage factor = 55 cm/year

Yearly recharge = 73.12x0.55=40.21 ham

(iv) Gross Annual Recharge:

= 6324.18 + 312.30 + 132.73 + 3640.92 + 40.21

= 11667.34 ham

(v) Net Annual Recoverable Recharge

= 85/100 x 11667.34 = 9917.23 ham

GROUNDWATER DRAFT:

(i) Draft by dugwells:

No. of dugwells = 2813, unit draft = 1.40/year

yearly draf = 2813 x 1.40

= 3938.20 ham.

(ii) Draft by shallow tubewells/pump sets:

No. of shallow tubewells = 1586, unit draft/year

= 2 ham, yearly draft = 3172 ham.

(iii) Draft by deep tubwells:

No. of Deeptubewells = 50, unit draft/year = 18 ham

Yearly draft = 900 ham

A. Gross annual draft = 8010 ham

B. Net annual draft = 70/100 x 8010 = 5607 ham.

GROUNDWATER BALANCE:

= 9917.23 - 5607 = 4310.23 ham.

STAGE OF GROUNDWATER DEVELOPMENT:

(a) Present stage = 5607/9917.23 x 100 = 56.53%

(b) Stage at 5 years = 56.53 + 5 x 2 = 66.53%
Category = Grey or Semicritical

5.5 GROUNDWATER ASSESSMENT OF TAPPAL BLOCK:

ANNUAL RECHARGE:

(i) Monsoon recharge (ham):

1. Year of observations = 1992 to 1993
2. Total geographical area = 37300 hactares
3. Water table flucation = 1.03 m
4. Adopted specific yield = 18%
5. IMD Normal yearly rainfall = 616.3 mm
6. IMD Normal non-monsoon rainfall = 38.80 mm
7. IMD normal monsson rainfall = 552.4 mm
8. Average monsoon rainfall (yrs of obs.) = 664 mm
9. Infiltration factor = 25%
10. Gross Kharif draft = 1638.35 ham.

Monsoon recharge (ham) = (37300 x 0.18 x 1.03) + 1638.35 - (374.97 + 505.01) x 552.4/664.0 + 374.97 + 2483.46 = 7176.40 ham.

(ii) Non-monsoon rainfall recharge:
= 37300 x 0.0388x0.25 = 361.81 ham

(iii) Recharge from surface water sources:

(a) Recharge from canals:
Applied seepage factor = 15 ham/day/10^6 sq. m of wetted area of canal

1. Main canal:

Non-monsoon seepage = $7000 \times 15.27 \times 200 \times 15 \times 10^{-6}$

= 320.67 ham

Monsoon seepage = $7000 \times 15.27 \times 70 \times 15 \times 10^{-6}$

= 112.23 ham

Annual seepage = 432.90 ham

2. Distributaries:

Non-monsoon seepage = $48800 \times 9.16 \times 100 \times 15 \times 10^{-6}$

= 670.51 ham.

Annual seepage = 871.66 ham

3. Minors:

Non-monsoon seepage = $56100 \times 2.44 \times 100 \times 15 \times 10^{-6}$

= 205.32 ham

Monsoon seepage = $56100 \times 2.44 \times 30 \times 15 \times 10^{-6}$

= 61.59 ham

Annual seepage = 266.92

Total non-monsoon canal seepage = 1195.50 ham

Total monsoon canal seepage = 374.97 ham

Total annual canal seepage = 1196.50 + 374.97

= 1571.48 ham.

(b) Recharge from Irrigation water return flow:

1. Kharif crop:

Monsoon return flow = $15147 \times 0.40 \times 0.40$

= 2423.52 ham.

2. Rabi crop:

Non-monsoon return flow = $27059 \times 0.40 \times 0.30$

= 3247.08 ham

3. Sugar cane - I

Monsoon return flow = $1332 \times 0.15 \times 0.30$ = 59.94 ham.

Sugarcane-II

Non-monsoon return flow = $1332 \times 1.0 \times 0.30$ = 399.60 ham

Total yearly return seepage:
= Non monsoon seepage + monsoon seepage
= 3646.68 + 2483.46
= 6130.14 ham

(c) Recharge from Tanks & Ponds:

Nos of tank = 57, water spread area = 62.44 ha
Seepate factor = 55 cm/year
Yearly recharge = 62.44 x 0.55 = 34.34 ham.

(iv) Gross Annual Recharge:

= 7176.40 + 361.81 + 1196.50 + 3646.48 + 34.34
= 12415.73 ham.

(v) Net Annual Recoverable Recharge:
= 85/100 x 12415.73
= 10553.37 ham

GROUNDWATER DRAFT:

(i) Draft by dugwells:
Nos. of wells = 3939, unit draft = 1.0 ham
Yearly draft = 3939 x 1.0 = 3939 ham

(ii) Draft by shallow tubewells/pump sets:
Nos of shallow tubewells = 1454, Unit draft = 1.60ham
Yearly draft = 1454 x 1.60 = 2326.40 ham

(iii) Draft by Deep tubwells
Nos of deep tubewells = 18, Unit draft = 16 ham
Yearly draft = 18 x 16.0 = 288.0 ham.

A. Gross annual draft = 6553.40 ham
B. Net annual draft = 70/100 x 6553.40 = 4587.38 ham

<u>GROUNDWATER BALANCE:</u>

= 10553.37 - 4587.38

= 5965.99 ham

<u>STAGE OF GROUNDWATER DEVELOPMENT:</u>

a) Present stage = 4587.38/10553.37 x 100 = 43.46%

b) Stage at 5 years = 43.46 + 5 x 2 = 53.46%

Category = White or safe

5.6 GROUNDWATER ASSESSMENT OF NOJHIL BLOCK:

<u>ANNUAL RECHARGE:</u>

(i) Monsoon Recharge (ham):

1. Years of observation = 1992 & 1993
2. Total geographical area = 33805.0 hactares
3. Water table fluctuation = 0.86 m
4. Adopted specific yield = 12%
5. IMD Normal yearly rainfall = 624.0 mm
6. IMD Normal monsoon rainfall = 546.10 mm
7. IMD Normal non-monsoon rainfall = 55.0 mm
8. Average monsoon rainfall (yrs. of obs.) = 376mm
9. Infiltration factor = 25%
10. Gross Kharif draft = 1724.85 ham

Monsoon recharge:

= (33805x0.12x0.86) + 1724.85 - (389.67+77.23 + 517.46) x 546.10/376 + 389.67 + 77.23

= 6609.31 ham.

II. Non-monsoon rainfall recharge

= 33805 x 0.055 x 0.25

= 464.81 ham.

(iii) Recharge from surface water sources:

(a) Recharge from canals:

Applied seepage factor = 15 ham/day/10^6 sq. m. of wetted area of canal

1. Main canal:

Non-monsoon seepage = $15000 \times 15.27 \times 200 \times 15 \times 10^{-6}$

= 687.15 ham

Monsoon seepage = $15000 \times 15.27 \times 70 \times 15 \times 10^{-6}$ = 240.50ham

Annual seepage = 927.65 ham

2. Distributaries:

Non-monsoon seepage = $25000 \times 9.16 \times 100 \times 15 \times 10^{-6}$

= 343.50 ham.

Monsoon seepage = $25000 \times 9.16 \times 30 \times 15 \times 10^{-6}$

= 103.05 ham.

Annual seepage = 446.55 ham.

3. Minors:

Non-monsoon seepage = $42000 \times 2.44 \times 100 \times 15 \times 10^{-6}$

= 153.72 ham

Monsoon seepage = $42000 \times 2.44 \times 30 \times 15 \times 10^{-6}$

= 46.12 ham.

Annual seepage = 199.84 ham.

Total non-monsoon canal seepage = 1184.37 ham

Total monsoon canal seepage = 389.67 ham.

Total annual canals seepage = 1184.37+389.67

= 1574.04 ham.

(b) Recharge from irrigation water return flow:

1. Kharif crop:

Monsoon return flow = $33 \times 0.40 \times 0.40$ = 5.28 ham.

2. Rabi crop:

Non-monsoon return flow = $16146.0 \times 0.40 \times 0.30$

= 1937.52 ham.

3. Sugarcane - I

Monsoon return flow = 1599 x 0.15 x 0.30 = 71.95 ham

Sugarcane - II

Non-monsoon return flow = 1599x1.0x0.30 = 479.70 ham

Total annual return seepage:

= Non-monsoon seepage + Monsoon seepage

= 2417.22 + 77.23 = 2494.45 ham

(c) Recharge from Tanks & Ponds:

Water spread area = 45 ha, seepage factor = 55 cm/yr

Yearly recharge = 45 x 0.55 = 24.75 ham.

(iv) Gross Annual Recharge:

= 6609.31 + 464.82 + 1184.37 + 2417.22 + 24.75

= 10700.47 ham.

v. Net Annual Recoverable Recharge:

= 85/100 x 10700.47

= 9095.40 ham.

GROUNDWATER DRAFT:

(i) Draft by dug wells:

Nos. 3978, Unit draft/year = 1.4 ham.

Yearly draft = 3978x1.4 = 5569.20 ham.

(ii) Draft by shallow tubewells/pump sets:

Nos. = 719, Unit draft/year = 1.8 ham

Yearly draft = 719 x 1.8 = 1294.2 ham.

(iii) Draft by Deep tubewells

Nos. 2, Unit draft/year = 18 ham.

Yearly draft = 18x2 = 36 ham.

A. Gross annual draft = 6899.40 ham

B. Net Annual draft = 70/100 x 6899.40 = 4829.58 ham

GROUNDWATER BALANCE:

= 9095.40 - 4829.58
= 4265.82 ham

STAGE OF GROUNDWATER DEVELOPMENT:

(a) Present stage = 4829.58/9095.40 x 100 = 53.09%

(b) Stage at 5 years = 53.09+5 x 2 = 63.09%
Category = White or safe

5.7 ASSESSMENT OF GROUNDWATER RESOURCE POTENTIAL AND STAGE OF DEVELOPMENT:

The above block-wise evaluation of groundwater resource potential is summarized in Table 6.1 and the position of the entire investigated Yamuna-Karwan sub-basin is worked out.

According to the estimations, the utilizable groundwater resource potential of the Yamuna-Karwan sub-basin is 29566.0 ham, out of which 15023.96 ham. net draft is already being extracted for domestic and irrigational needs and 14542.04 ham. is available for further development.

In view of 50.81% of groundwater development, there is sufficient groundwater surplus available for further development in the sub-basin which can be utilized through the construction of about 100 deep tubwells with pumping rate of 70-120 m^3/hour at a drawdown varying between 4 to 6 meters. Besides it, about 1000 shallow tubewells having discharge of 15-25 m^3/hour at an economic drawdown may also

Table 5.1: Block-wise Assessment of Groundwater Resource Potential of Yamuna-Karwan Sub-basin during 1992-1993

Block	Total Geographical Area (ha)	Gross ground water recharge (ham.)	Net ground water recharge (ham)(85% of gross W.R.)	Gross groundwater draft (ham)	Net ground water draft (ham) (70% of gross draft)	Ground water balance available (ham)	Stage of groundwater Development (%)	
							Present	At five years
Khair	32196.33	11667.34	9917.23	8010.00	5607.00	4310.23	56.53%	66.53% (grey)
Tappal	37300.00	12415.73	10553.37	6553.40	4587.38	5965.99	43.46%	43.46% (white)
Nojhil	33805.00	10700.47	9095.40	6899.40	4829.58	4265.82	53.09%	63.09% (white)
Entire Yamuna-Karwan sub-basin	103301.33	34783.54	29566.00	21462.80	15023.96	14542.04	50.81%	60.81% (white)

be constructed in a phased manner over a period of 5 years, observing the effect of groundwater development and water level trend from time to time. This will create an additional irrigation potential in the sub-basin.

However, a constant monitoring of water level in the sub-basin is very much required to keep a watch on the groundwater regime all over the area. The numerous distinct groundwater troughs developed in the areas close to the left bank of the river Yamuna over the years due to the excessive development of groundwater need special attention. In all such places recharge thorough canal network be arranged in order to contain the rapidly declining trend of the water table converting an effluent river Yamuna into an influent one. Moreover, water logging all along the feeder canal (Mat branch) be checked as early as possible through lining of the feeder canal beds. this will increase the canal efficiency and will also save water, which infiltrates down below the canal beds which can be utilised for irrigating many more hactares of land on the Yamuna banks or on the down stream side of the canal.

CHAPTER - VI
HYDROCHEMISTRY

HYDROCHEMISTRY

Groundwater forms a major source of drinking water for urban and rural water supplies in India. Since quality of public health depends to a great extent on the quality of drinking water, it is imperative that indepth information about the quality of water be systematically collected and monitored (Biswas and Saha, 1983). Apart from quantity, quality of groundwater is equally important in determining the suitability of a particular groundwater for a certain use (Public Water Supply, Irrigation, Industrial Application, Cooling, etc.). The water being universal solvent, its purity can not reamin intact. The chemical quality of groundwater is an index of its complex flow history and is the resultant of all processes and reactions that have acted on the water from the moment it condensed in the atmosphere to the time it is discharged by a well or spring. Therefore, the quality of groundwater varies from place to place, with the changes in the depth of water table and from season to season, it is primarily governed by the extent and composition of dissolved solids in it. The kind and concentration of dissolved solids in it, depends upon source of salts and subsurface environment, movement, and source of the groundwater.

The intensive use of natural resources and large production of wastes in modern society often pose a threat to groundwater quality and has already resulted in many incidents of groundwater contamination. Degradation of groundwater quality can take place over large areas of plain or diffuse sources like deep percolation from intensively cultivated fields or it can be caused by point sources such as septic tanks, garbage disposal sites, mine spoils, oil spills or other accidental entry of pollutants into the underground environment. A third possibility is contamination by line sources of poor quality water, like seepage from polluted streams (Khurshid and Israili, 1988).

Salts are also added to the groundwater while it is passing through the soils which has soluble products of soil weathering and erosion by rainfall and flowing water. Excess irrigation water percolating to the water table may contribute substantial quantities of salt. Use of excessive quantities of fertilizers, pesticides, etc. can also causes the quality problem of the water.

Because groundwater tends to move very slowly, therefore many years may elapse between start of pollution and its reflection in a well. For the same reason, many years may be required to rehabilitate contaminated aquifers after the source of pollution has been eliminated. This long delay can force abondonment of wells and may require costly development of alternate water supplies. Prevention of contamination thus is the best way for protecting ground water quality. Water drawn from strata at a particular time of the year may be unsuitable whereas it may be good enough at the other times of the year.

The minerals carried in water, determine its usefulness for various purposes. Presence of some ions, beyond a certain limit, may make water injurious for irrigation, drinking and industrial purposes. Hence, it becomes necessary to monitor the groundwater quality in an area to assess its suitability for various uses. Groundwater quality variation problem can be understood only by the regular monitoring of quality of water. In the present chapter same has been discussed in detail.

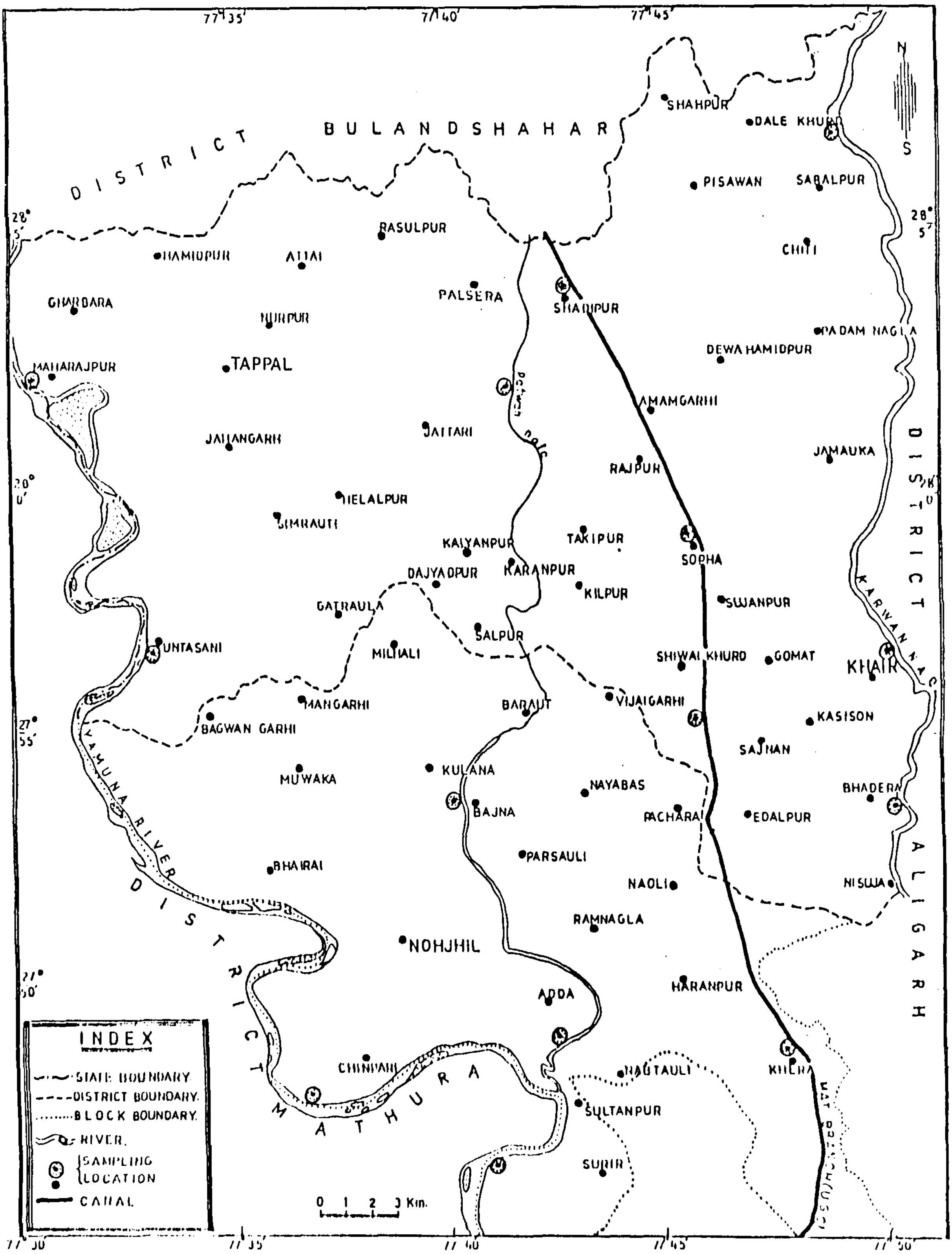


Fig. 6.1: Map showing the sampling location in the study area.

In order to study water quality in the study area, samples from surface and sub-surface water bodies were collected. About 60 water samples were collected during June, 1992 from different groundwater structures spread over the entire area (Fig. 6.1). Besides it, 30 water samples were randomly collected during June, 1993 to check the change in water quality, if any. Out of 60 samples, all were analysed for major elements and 40 samples were analysed for trace element studies.

Similarly water samples collected from the Yamuna and Karwan rivers, Patwah nala and Mat branch (canal) were analysed for major and trace element studies.

6.1 METHODOLOGY AND MATERIALS USED:

Sampling Techniques:

Sampling is one of the most important and foremost step in collection of representative water sample for surface or subsurface water quality studies.

The samples for major ion chemistry were collected in well cleaned 500 ml. capacity double stoppered polythene bottles during the year 1992 and 1993. Prior to sampling the bottles were carefully cleaned with concentrated HCl then rinsed with tap water and finally with distilled water. The bottles were then dried at 103°C for one hour, cooled to room temperature and capped. Before the collection of the samples these water sample bottles were rinsed with the water to be sampled. the samples were taken from different groundwater structures like open wells, shallow and deep tubewells as per the normal procedures

(Handa, 1989). Forty water samples were collected in one litre capacity bottles duly acidified with 10 ml 6N HNO_3 for the trace elements studies. Similarly, samples for major and trace elements studies were collected from surface water bodies such as rivers canals traversing through the study area. Samples after collection were capped and sealed with wax immediately in the field.

Analytical Procedure:

The water samples were analysed as per the standard methods, (APHA, 1975; Jackson, 1958; Trivedi and Goel, 1984) in the Environmental Geology Lab., A.M.U., Aligarh. Samples for trace elements analyses were filtered through Whattman filter paper no. 42 and 500 ml. of the filtered samples were acidified again with 5 ml of 6N HNO_3 before concentrating to 50 ml (Parker, 1972). The concentrated samples were analysed through ICP spectrophotometer (Inductive copuled plasma spectrophotometer) and the heavy metals like Zn, Cu, Fe, Mn, Pb, Cr, Cd and Sr were determined at Wadia Institute of Himalayan Geology, Dehradun. A blank sample was made for each spectrophotometric analysis in order to account for any instrumental error. Sodium and potassium were analysed through flame photometer in the Department of Geology, A.M.U., Aligarh. The analytical techniques adopted for the estimation of various constituents is given in Table 6.1.

Table 6.1: Analytical techniques for chemical analysis.

S.No.	Constituents	Techniques adopted
1	pH	Digital pH meter
2	EC	Conductivity meter
3	CO_3^{--}	Titration

4.	HCO^{-}	Titration
5.	Cl_{3}^{-}	Titration
6.	SO_{4}^{--}	Turbidimetric
7.	F^{-}	Fluorimeter
8.	Total Hardness	Titration (EDTA)
9.	Total Dissolved Solids (T.D.S.)	Volumetric
10.	K^{+}	Flame-photometer
11.	Na^{+}	Flame-photometer
12.	Ca^{++}	Spectrophotometer
13.	Mg^{++}	Spectrophotometer
14.	Trace elements	Inductive coupled plasma Spectrophotometer

6.2 ANALYTICAL RESULTS:

The quality of water depends on a large number of individual hydrological, physical, chemical and biological factors.

Some parameters are of special importance and deserve frequent attention and observation, other gives a rough picture of water body and its quality status.

During the present study the following constituents of surface and sub-surface water that were analysed are shown in Table 6.2.

Table 6.2

Physical Para-meters	Chemical Para-meters	Major cations	Major anions	Trace elements
Electric conductivity	pH value	Calcium (Ca^{++})	Bicarbonates (HCO_3^-)	Iron (Fe)
	Total dissolved solids (T.D.S.)	Magnesium (Mg^{++})	sulphate (SO_4^{--})	Copper (Cu)
	Total Hardness	Sodium (Na^+)	Chloride (Cl^-)	Zinc (Zn)
		Potassium (K^+)	Carbonates (CO_3^{--})	Manganese (Mn)
			Flouride (F^-)	Lead (Pb)
				Cadmium (Cd)
				Chromium (Cr)
				Strontium (Sr)

The analytical results of the mentioned constituents in the water samples collected from observation wells, rivers and canals are given in Appendices (IX-A, X-A, X-B, XI-A, XII-A & XII-B).

Hydrogen ion concentration (pH):

The pH refers to the activity of hydrogen ion concentration in the water, expressed as the negative logarithm (base 10) of the H^+ activity in moles per litre. At a pH of 7, the H^+ activity is 10^{-7} mol/l and the solution behaves as neutral while the pH is less than 7 behaves as an acid. Further, at pH above 7, the solution is indicative of alkaline character. The European standards for the drinking water as suggested by World Health Organisation (W.H.O.) do not give any range of values for the pH. However, in the international edition of W.H.O., it is said that low pH is likely to give rise to off taste and to promote corrosion. The highest desirable limit quoted is 7 to 8.5 while the maximum permissible limit is given as 6.5 to 9.2. In the report of the committee on water quality criteria of U.S. Department of Interior the permissible range is given as 6.5 to 8.5. The above range of value was suggested as desirable criteria.

In general, the groundwater in the area is moderately alkaline in reaction. pH generally was found to vary from 7.4 to 9.06 during the year 1992, while in June, 1993 it ranges between 7.5 to 9.04. The pH values of the groundwater samples of the study area indicate that though the groundwater is alkaline in reaction but it falls well within the limit.

Electrical Conductivity (Micro-mhos/cm at 25^{o}C) :

Electric conductivity is a measurement of water's capacity for conveying electrtic current and is directly related to the concentration of ionized substance in the water. It is the measure of the mineralization and indicative of the salinity of groundwater.

The electric conductivity with 400 micro-mhos/cm at 25^{o}C is considered suitable for human consumption. In the study area, electrical conductivity, values of water samples were found to range between 300 to 7200 micro-mhos/cm. The electric conductance map (Fig. 6.2) shows the electrical conductivity distribution in the study area. A perusal of figure indicates that in the major parts of the area electrical conductivity ranges between 700 to 1500 mhos/cm. The highest values (7200 micro-mhos/cm) was recorded at Salpur

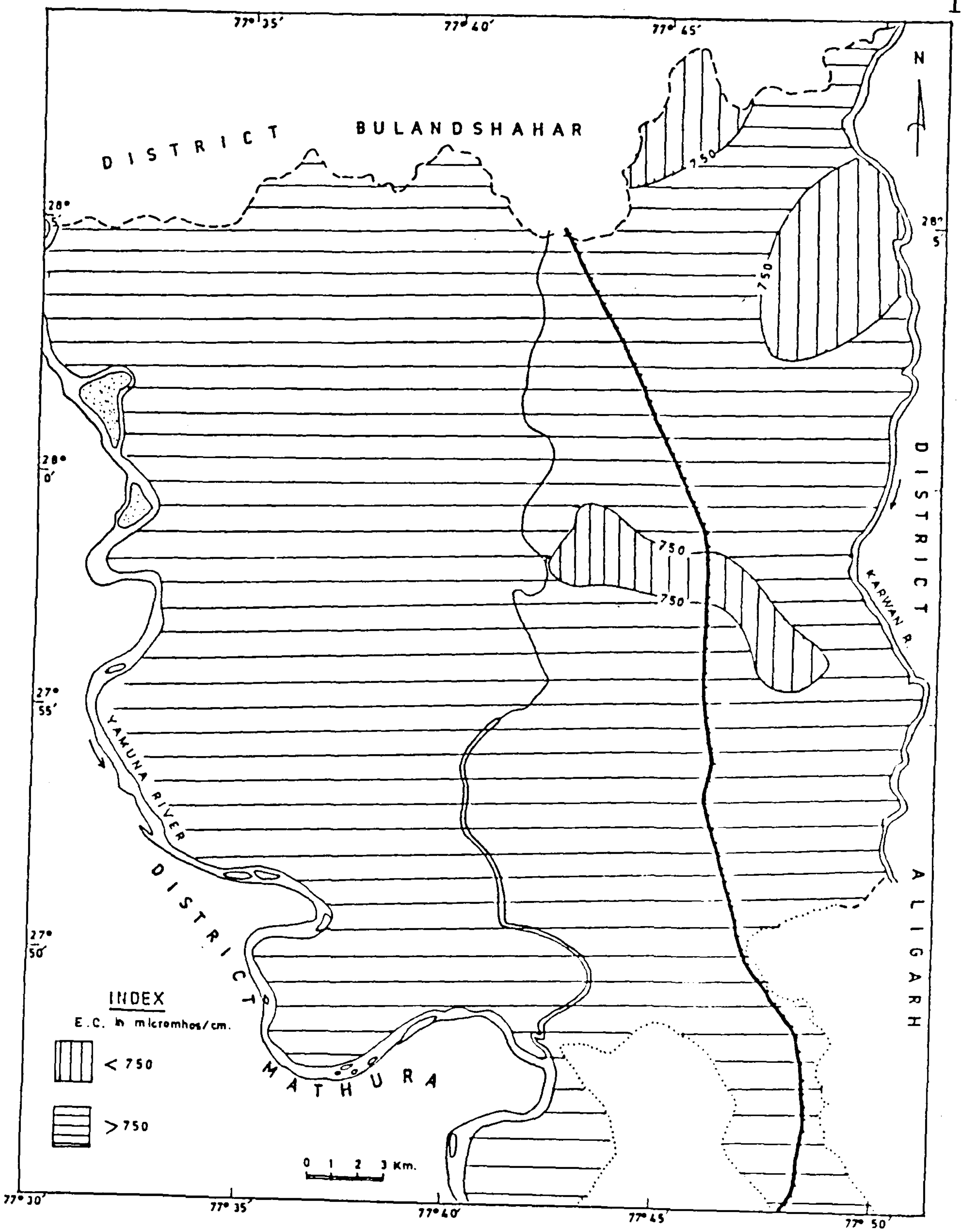


Fig. 6.2: Electrical conductivity map of the area.

in Khair, while the lowest value (300 micro-mhos/cm) was recorded at Shahpur village. These considerably high values of electrical conductivity are possible due to thick clay beds which do not permit flushing and dilution through recharge.

6.2.1 MAJOR ELEMENTS :

Chloride :

Chloride is one of the major inorganic anion in water. It is present in all potable water supplies and in sewage, usually as a metallic salt. High chloride concentration in water give an undesirable taste to water and beverages and large amounts may act corrosively on metal pipes and may be harmful to plant life. Lockhart et al. (1955) have reported that the taste thresholds for chloride ion in water varied from 210 to 310 mg/l. However, infants and young children may suffer if they consume water high in chloride as their delicate kindey tissues may be damaged by the higher osmotic pressure brought about by the presence of high concentration of salts. It is, therefore, important that the chloride content of water supplies should be kept as low as possible.

The Indian Council of Medical Research (I.C.M.R., 1975) recommends 200 mg/l desirable limits of chloride in potable water and 1000 mg/l as the maximum permissible limit. The W.H.O. (1984) suggests the 200 mg/l as desirable limit and 600 mg/l as permissible limit of chloride in drinking water.

The analytical results indicate that the chloride concentration varies from 46 to 1230 ppm in the study area. The study of the isochlore map (Fig. 6.3) shows that at Surir in Nojhil block the value is 1230 ppm. and in most of the area the value ranges between 50 to 600 ppm.

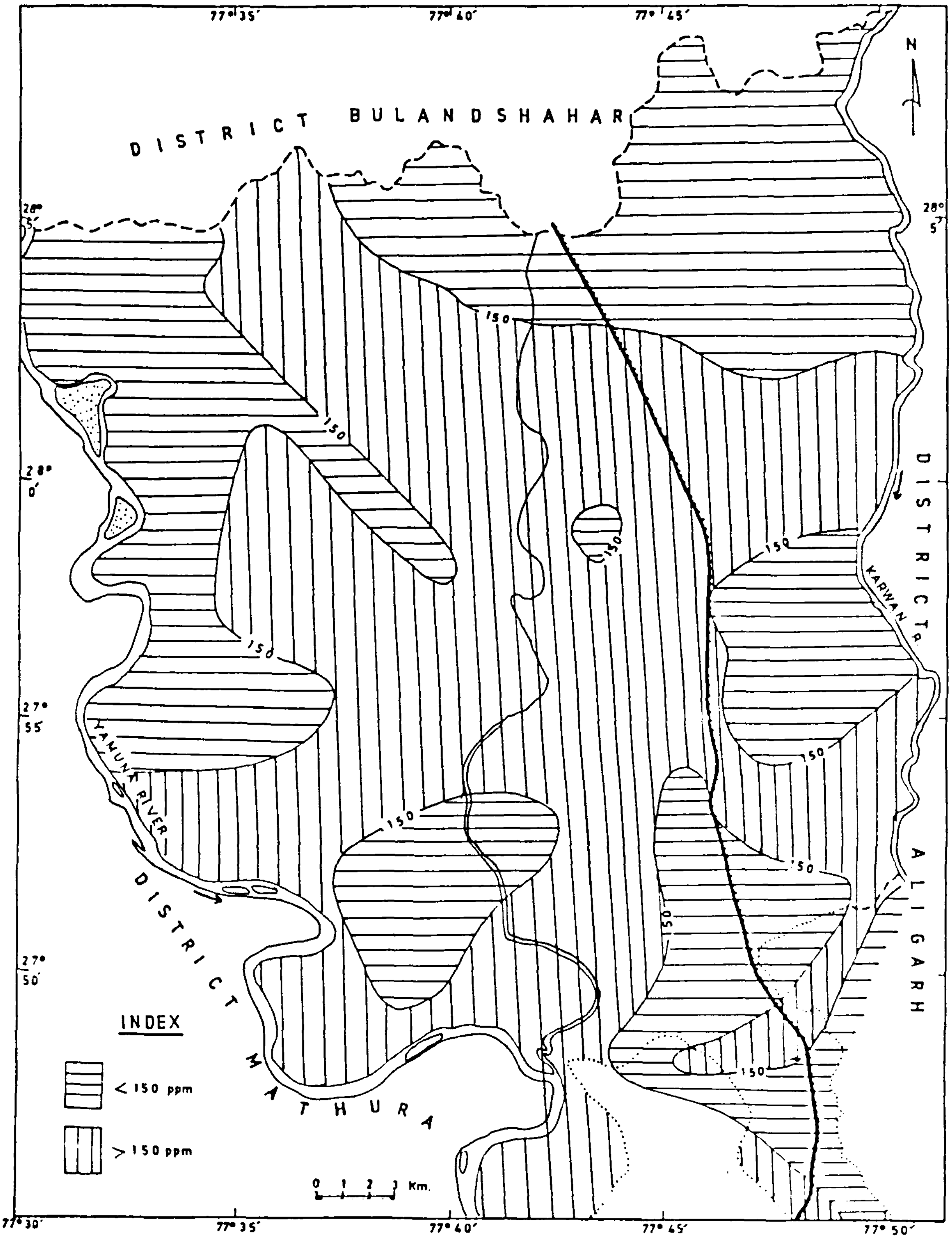


Fig. 6.3: Chloride distribution map of the area.

Carbonates :

The concentration of carbonate was found to range between 8 to 46 ppm during June, 1992 and between 8 to 42 ppm in 1993.

Bicarbonates :

Bicarbonates and carbonates are the most common cause of alkalinity in natural water. The bicarbonate content in groundwater depends upon the partial pressure of the carbondioxide in soil and represent the major form since they are formed in considerable amounts from the action of carbonates upon the basic materials in soils.

$$CO_2 + CaCO_3 + H_2O \longrightarrow Ca\,(HCO_3)_2$$

The bicarbonate concentration in the study area was found to range between 24 to 842 ppm during June, 1992 and 76 to 799 ppm during 1993. The groundwater containing 600 ppm of bicarbonate is considered fairly safe and good for irrigation and domestic purposes. A perusal of (Fig.6.4) and Appendix-XI-A shows that concentration of bicarbonate lies within the permissible limits in the study area.

Sulphate :

Sulphate appears in natural waters in a wide range of concentrations and has no charcteristic action on the soil other than increasing its salinity. High concentration of sulphates in association with sodium or magnesium in the drinking water might give rise to gastrointestinal irritation. At higher conentration sulphate can have laxative effect (W.H.O., 1984). Water containing magnesium sulphate at levels 1000 mg/l acts as purgative in adults while lower

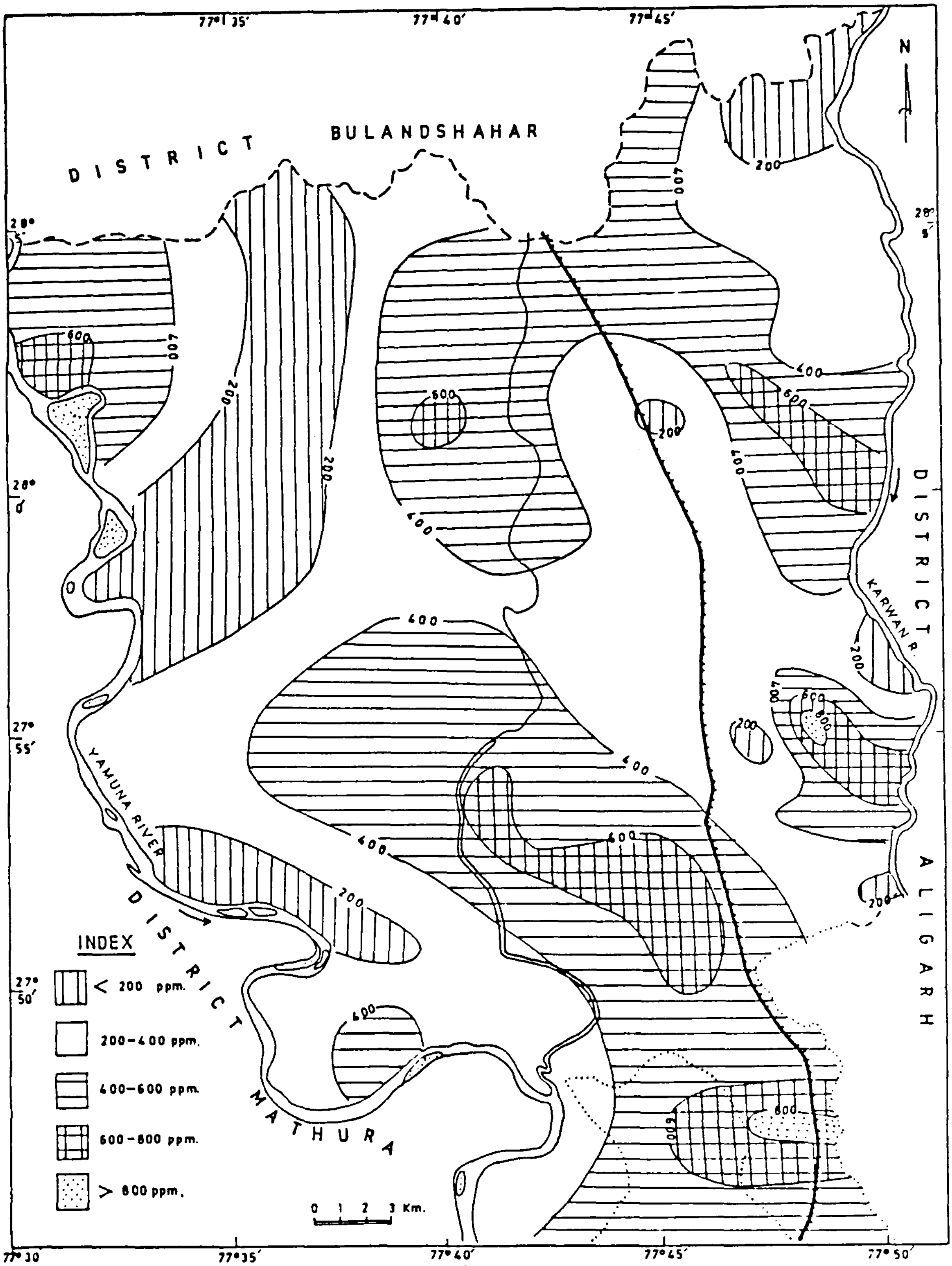


Fig. 6.4: Bicarbonate contour mpa of the area.

concentration may affect new users and children. Sulphate generally have less affect on taste than chlorides and carbonates. Taste threshholds vary according to the associated cations and are in the range of 200-500 mg/l.

The sulphate concentration in water samples of study area was found to range between 33 to 680 ppm during 1992 and 42 to 598 ppm during the year 1993. The overall concentration of sulphate in the study area is within the safe limit.

Sodium :

Sodium is present in nearly all natural waters and its concentration in drinking water depends on factors such as hydrogeological conditions, the season of the year and industrial activities. Ratio of sodium to total cations is important in agriculture and human pathology. Higher concentration of sodium is considered harmful to persons suffering from cardiac and renal diseases. Moreover, the sudden death of infants could be associated with the high sodium contents of the artificial feeds prepared with water containing high sodium content and dried cow milk.

The guideline value of sodium is given as 200 mg/l which is based on taste consideration (W.H.O., 1984). The concentration of sodium in the groundwater of the study area was found to range between 22 to 800 ppm during June, 1992 and between 30 to 810 ppm during June, 1993. The highest concentration of sodium (800 ppm) was recorded in the groundwater sample collected from Salpur Observation well. The higher concentration may possibly be due to lithological control.

Potassium :

Potassium is less common cation in the groundwater.

Potassium, being the most mobile cation apart from an involvement in metabolic processes. These ions participate in nerve impulse conductive via the brain (Forstner and Wittmann, 1979). Potassium salts are of therepeutic value in the treatment of familiar periodic paralysis while no desirable or excessive limit for potassium have been set, though 1000-2000 mg/l seems to be the extreme limit for K-ion in drinking water.

The analytical results shows that the concentration of potassium varies from 2.5 to 500 ppm during June, 1992 and 4 to 465 ppm during June, 1993. The concentration of K is generally low in groundwater of the area.

Calcium :

Calcium is one of the principle cations in groundwater. The dissolved CO_2 generally control the Ca^{++} ion concentration in the groundwater (Pathak, 1980). The calcium is most abundant element in human body, which requires 0.7 to 2.0 gm/day. However, larger doses may be required by pregnant women, those who are breast feeding or growing children. It helps in the formation of bones and teeth in which calcium is deposited as hydroxyl apatite (Vahrenkamp, 1973). The absence of calcium in very soft water has been considered responsible for rickets and defective teeth etc. While hard water having high calcium concentration causes gout rheumatism and urinary disorders etc. The limits of calcium in drinking water are not based on health consideration as even water having 100 mg/l of calcium is harmless. An average daily adult requirement of calcium is 10 mg/kg of body weight and for growing children 40.6 mg/kg of body weight. The highest desirable level of calcium in drinking water is 75 ppm and maximum permissible level is 200 ppm (W.H.O., 1984; I.C.M.R., 1975).

The concentration of Ca in the groundwater of the area ranged between 10 to 125 ppm during June, 1992 and 12 to 120 ppm during June, 1993. The values recorded for calcium are well within the limit.

Magnesium :

After calcium, magnesium is the most important alkaline earth metal present in the grounwater . It is one of the most important contributor to the hardness of water. The magnesium concentration depends upon the source of water. Lower concentration of magnesium is not harmful but higher concentration are laxative. Maximum acceptable and allowable limit of magnesium in drinking water according to W.H.O. (1984) is 30 ppm and 150 ppm, respectively and I.C.M.R. (1975) has given 50 ppm as an acceptable and 100 ppm as the permissible limits for the magnesium.

The magnesium content of groundwater samples ranges between 16 to 160 ppm during 1992 and 18 to 155 ppm during June, 1993. Most of the groundwater samples of the study area are within the prescribed limits.

Total Hardness :

Hard water contains calcium and magnesium ions. Hardness is generally defined as the calcium carbonate equivalent of calcium and magnesium ions present in water as expressed in ppm. There is evidence that death rates from cardiovascular diseases are inversely correlated with the hardness of water, but there is insufficient studies to indicate whether the calcium or the magnesium in water is directly involved in it. Public acceptability of the degree of hardness of water may vary considerably from one community to another, depending upon local conditions, and in some instance a water hardness in excess of 500 mg/l is tolerated.

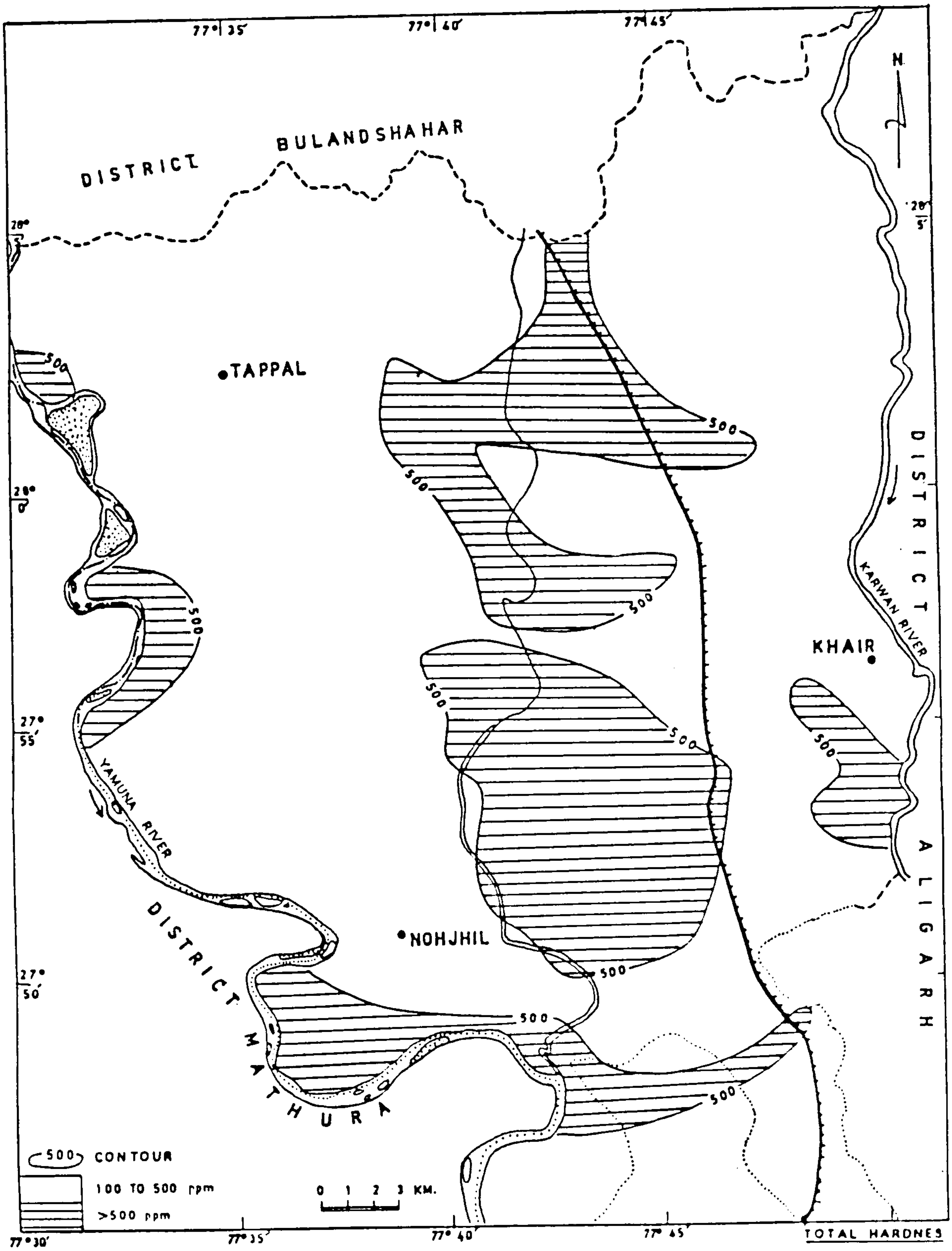


Fig. 6.5: Total hardness map of the area.

Associated anions depending upon the taste threshold for the calcium ion is in the range of 100-300 mg/l. The interaction of other factors, such as pH and alkalinity, water with a hardness above approximately 200 mg/l may cause scale deposition in the distribution system. the guideline value for hardness at 500 mg/l (as $CaCO_3$) is based on taste and household use consideration (W.H.O., 1984).

In water samples of study area, total hardness as $CaCO_3$ ranges between 150 to 1020 ppm. The highest value (1020 ppm) was recorded at village Salpur. Figure 6.5 shows the total hardness distribution in the study area.

Hardness is expressed in term of ppm of calcium carbonate on the basis of which following classification is used.

S.No.	Class	Range of hardness as $CaCO_3$ (ppm)	Percentage
1.	Soft	0 - 60	nil
2.	Moderately	61 -120	nil
3.	Hard	121 -180	16.66
4.	Very hard	180	83.33

On the basis of degree of hardness it has been observed that the groundwater in the area is generally hard to very hard in nature.

Total Dissolved Solids :

The total dissolved solids consist of inorganic substances. The principal constituents of TDS are calcium, magnesium, sodium, bicarbonates, chlorides and sulphates. It is the main characteristic which measures the suitability of water for irrigation. An important aspect of TDS, with respect to drinking water quality, is the effect on taste.

The palatability of water with a TDS level less than 600 mg/l is generally considered to be good whereas at TDS levels greater than 1200 mg/l drinking water becomes increasingly unpalatable (W.H.O., 1984). Indian Council of Medical Research (1975) while recommending 500 ppm TDS in potable water has also laid down maximum permissible limits of 1500 mg/l TDS where no alternative shource is available. Davis et al. (1966) has given a classification of water based on TDS as follows :-

Types of Water	Concentration of Total Dissolved solids in ppm
Fresh water	0 - 1000
Brakish water	1000 - 10,0000
Salty water	10,0000 - 100,0000
Brine	More than 100,0000

The values of TDS in the groundwater of the area ranges between 200 to 2150 ppm during June, 1992 and 198 to 2080 ppm during 1993, which put the groundwater of the area into fresh to brakish category. A perusal of Figure 6.6 shows that most of the area falls under the fresh category.

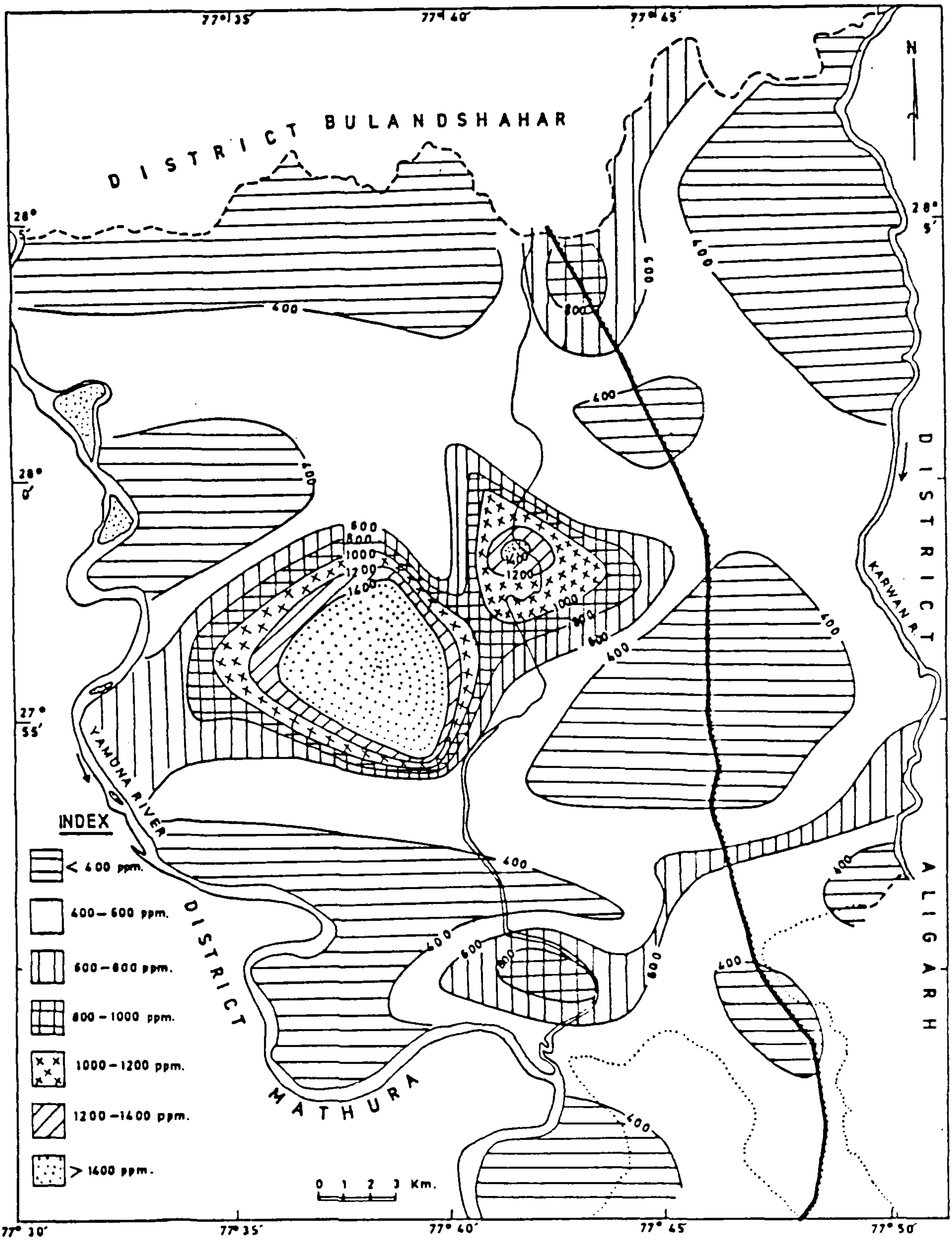


Fig. 6.6.: Map showing the distribution of total Dissolved solids in the area.

Fluoride :

Fluoride is naturally present in some foodstuffs as well as in water. There is no evidence of harmful effects associated with the relatively low levels to which people are commonly exposed. It becomes toxic to animals and human beings when present at more than 1 mg/l concentration in drinking water (Galagan and Vermilliaan, 1957). At levels above 1.5 mg/l, mottling of teeth has been reported very occasionally, and at 3.0 - 6.00 mg/l. Skeletal flurosis may be observed, when a concentration of 10 mg/l is exceeded, it may cause crippling problem. Cargo and Mallory (1977) have suggested that due to the intake of fluoridic water for a long time, gradual decrease in both the amount and strength of bones take place. Jolly et al. (1974) reported that fluoride ingestion predominantly comes from drinking water, and the contribution of fluorides from various food items is not very significant in the cases of chronic fluoride intoxication . Since the recommendations on fluoride content were made and published in the international standards of drinking water, there has been no generally accepted evidence that would justify any change in the guideline value. Mottling of teeth are sometimes associated with fluoride levels above 1.5 mg/l in drinking water, this concentration is recommended as the guideline value (W.H.O., 1984).

The concentration of fluoride in shallow groundwater ranged between 0.07 to 1.89 ppm (1992) and in case of deep groundwater it ranged between 0.05 to 1.01 ppm (1992). No significant change has been found in the concentration of fluoride during the years 1992 and 1993.

A perusal of Figure 6.7 shows that fluoride concentration in shallow groundwater of Musandgarhi, Jarara, Ramnagla, Adda and Bera villages of Nojhil block is having higher values than the permissible limit of 1.5 mg/l.

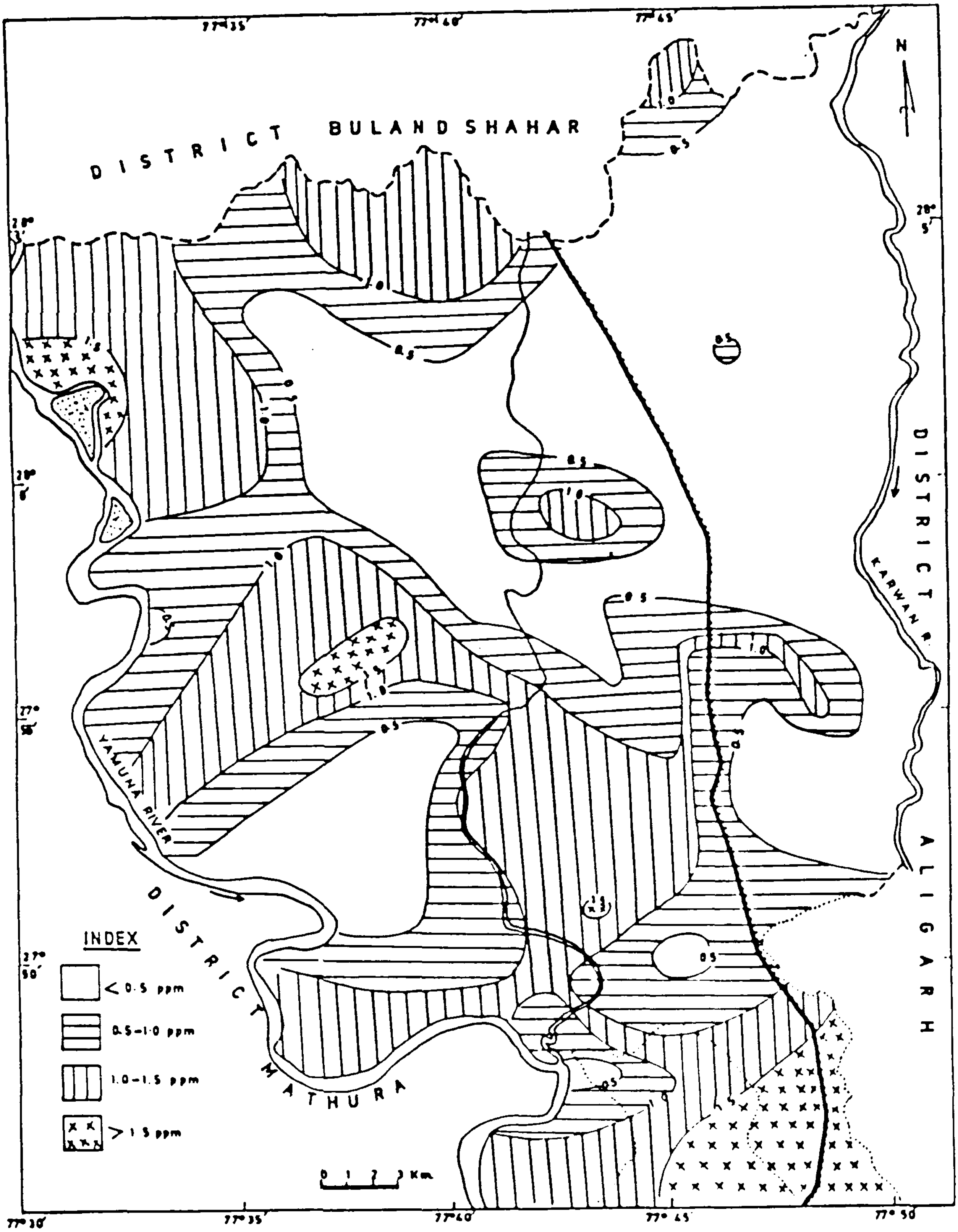


Fig. 6.7: Map showing the distribution of fluoride in the study area.

6.2.2 TRACE ELEMENTS :

The elements present in the water in very low concentration known as trace elements, which play a very important role in the human and animal metabolism and healthy growth of plants (Handa, 1983). Although, trace quantities of certain elements exert a positive or negative influence on plant, animal and human life, which get a part of total intake of these trace constituents through diet or food, a part may also be supplied through the medium of drinking water and beverages. Deficiencies of 20-24 elements in animals and man (Friedin, 1972) and 13-17 elements in plants have been recognised (Epstein, 1965). The growing public concern over the deteriorating quality of the environment has led to a generalized usage when referring to trace elements. Thus for practical purposes, other terms such as 'trace metals', 'trace inorganics', 'heavy metals', 'micro-elements' and 'micro-nutrients' is treated as synonymous with the term trace elements (Forstner and Whittmann, 1979).

It has been borne by experimental evidence that the role of heavy metal ions in lining system follows the pattern of natural availability and abundance of the same metal occurring in nature. Metal containing industrial effluents constitute a major source of metallic pollution of the hydrosphere, another source is the movement of drainage water from catchment areas which have been contaminated by waste from sugar factories and various metal, chemical, electroplating and paper industries (Khurshid et al., 1992).

Water samples from shallow and deep aquifers were collected for the determination of trace elements like, Fe, Cu, Zn, Mn, Pb, Cd, Cr, and Sr. The concentration of these heavy metals was found more in water of shallow aquifers than of the deeper aquifers. The probable cause may be due to excessive use of fertilizers, pesticides, herbicides, agriculture waste, dumping of untreated industrial wastes, household refuses, sewage disposal, transport and power generation, etc. The results of chemical analysis are given in (Appendices - X-A & X-B). The total concentration of trace metals in groundwater of the study area and their various health hazards are discussed below :-

Iron :

Iron is most abundant transition element and probably the most well known metal in biologic system (haemaglobin in blood is regarded as the most important iron user). Natural water contains variable but minor amounts of iron despite its universal distribution and abundance. Iron can enter into a water system by leaching natural deposits, effluent from picking operations, or acidic mine drainage. Iron is highly toxic element only when it crosses the permissible limit. Although iron is essential element in human nutrition (W.H.O., 1984) but become toxic when administered parenterally (Fairbanks et al., 1971).

The presence of iron can give rise to an astringent taste, discoloration, deposit of rust and could promote the growth of iron bacteria (Riddick et al., 1958). Taste thresholds of iron in water are 0.1 ppm ferrous iron and 0.2 ppm ferric iron, giving a bitter or astringent taste to the water. Domestic water supplies containing more than 0.3 ppm total iron should be rejected due to staining and taste considerations.

W.H.O. (1984) has recommended the guideline value for iron as 0.3 mg/l. Iron occurs in most of the groundwater samples of the area and its concentration ranges between 0.041 to 2.681 ppm in shallow aquifers while in deeper aquifer it varies between 0.01 to 0.40 ppm. The highest value of iron (2.681 ppm) was recorded at Untasani village of Tappal block. A perusal of appendix indicates that iron concentration is within the permissible limit except at some places.

Copper:

Copper is an essential element in human metabolism (W.H.O., 1973) and is considered to be non-toxic for man at 0.05 mg/l level in drinking water. The greatest danger of toxicity arises when children consume acidic beverages that have been in contact with copper container or valves (Food and Drug Administration, 1975). There is a report of an infant fatality associated with the drinking of water that contained copper at 6.75 mg/l for 14 months. Copper concentration ranged between 0.012 to 0.062 ppm in shallow aquifer and 0.001 to 0.048 ppm in deeper aquifers. The analytical results (Appendix - X-A) show that the overall concentration of Cu in the study area is well within the permissible limits (W.H.O. (1984) and I.S.I. (1983).

Zinc:

Zinc is an essential and beneficial element in human metabolism and is not a danger to health except at extremely high concentrations. The daily requirement is 4-10 mg depending on age and sex. The zinc deficiency in children leads to the growth retardation.

Water containing zinc at concentration in excess of 5.0 ppm has an undesirably astringent taste and may be opalescent, developing a greasy film on bioling (W.H.O., 1984).

The concentration of zinc in the groundwater samples of shallow aquifers ranges from 0.981 to 5.048 ppm while in deeper aquifer it ranges from 0.456 to 1.128 ppm which is well within the prescribed limit.

Lead:

The toxicity of lead has been known to mankind for many centuries. Lead is a toxic metal and tends to accumulate in the tissues of man and animals, children and infants, and even in feutses in utero. The pregnant women are most sensitive to environmental lead exposure. W.H.O. (1977), Synder et al. (1971) have described the effect of lead poisoning on man. Chishobn (1971), and Croyer and Rhyne (1973) have reported that elevated lead disrupts the blood enzyme delta-amino levulinic acid dehydrates (ALAD) activity in human and can induce a reduction in haemoglobin. Lead in high doses has been recognized for centuries as a cumulative general metabolic poison. Some of the symptoms of acute poisoning are tiredness, lassitude, slight abdominal discomfort, irritability and anaemia (W.H.O., 1984).

As per recommendation of (W.H.O., 1984; I.S.I., 1983) the highest desirable level of lead in drinking water is 0.1 mg/l. The water samples of shallow aquifer in the study area shows that it ranges between 0.025 to 0.501 ppm while in deeper aquifers its concentration ranges from 0.002 to 0.198 ppm.

The table shows that lead concentration is higher in most of the study area which needs special attention as it may cause the toxic effect on the habitants.

Manganese:

Manganese is found in groundwater as the divalent ion (Mn^{++}) due to lack of subsurface oxygen. At higher concentrations, it causes undesirable taste in beverages. In common with iron, its presence in drinking water may lead to the accumulation of deposits in the distribution system (W.H.O., 1984). Manganese may cause neurological syndrome if taken at higher concentration (Annon, 1977).

The concentration of manganese ranges from 0.029 to 0.795 ppm in shallow groundwater samples while in deeper aquifer samples, manganese concentration varies between 0.01 to 0.057 ppm. At places the manganese concentraton is higher than its permissible limit of 0.05 ppm as recommended by W.H.O. (1984).

Cadmium:

Cadmium is highly toxic to man and animals (Friberg et al., 1974), but it is widely distributed in the environment in trace amounts. Cadmium in high concentration is a deadly poison, but even small amounts of cadmium taken over a long period of time accumulates in the body and causes serious illness (Verma, 1987). Excessive exposure to cadmium was resulted in severe health effects (W.H.O., 1984). Cadmium gets accumulated and is retained mainly in the liver and kidney, thus causing pathological changes of the hepatocyles of the liver and kidney, tubules and glomeruli changes (Itokawa et al., 1974; Colucci et al., 1975). The most common abnormality from chronic cadmium exposure involves renal toxicity, urine concentrating ability (Drinking Water and Health, 1980). There have been no reported effects from the low level of cadmium that can be found in drinking water. The sources of cadmium contamination in water are seepage of cadmium into groundwater from the electroplating plants and from zinc galvanized iron in which cadmium is a contaminant.

The cadmium level detected in the shallow groundwater of the study area ranges between 0.002 to 0.041 ppm while in deeper aquifer its concentration ranges between 0.001 to 0.021 ppm. The analytical results show that the concentration of cadmium in the shallow groundwater is slightly higher than the prescribed limit at some places which may be hazardous for human population of these areas.

Chromium:

Chromium is one of the least toxic of the trace elements on the basis of its over supply and essentiality. Because of the low solubility of chromium, generally, the levels found in water is usually low (9.7 ug/litre) (National Academy of Science, 1974). Trivalent chromium rarely occurs in drinking water. Most water borne chromium is in the hexavalent form. Hexavalent chromium is much more toxic than trivalent chromium but it has no nutritional value and may be absorbed through the skin and by inhalation and corrosion (U.S. Environmental Protection Agency, Part II, 1983). Sign of toxicity by these compounds include hemorrhage of the gastrointestinal tract, ulcer of the nasal septum and carciogenic effect on respiratory tract (National Academy of Science, 1974). The maximum permissible limit of Cr^{+6} in drinking water is 0.05 mg/l (W.H.O., 1984). The chromium concentration in the shallow groundwater of the study area varies from 0.0298 to 0.0486 ppm. It is within permissible limit in both shallow and deeper groundwater.

Strontium:

Strontium behaves very much like calcium and found in water in traces. It has no toxic effect on human. The concentration of Sr in the shallow aquifer samples varies from 0.009 to 1.941 ppm and in deeper aquifers it ranges between 0.007 to 0.992 ppm.

6.3 GRAPHICAL REPRESENTATION OF CHEMICAL DATA:

Results of analysis of chemical quality of groundwater may be difficult to interpret. To overcome this, graphic representations are useful for comparing analyses and emphasizing similarities and differences. A variety of graphic techniques have been developed for showing the major chemical consituents. Following graphical methods are used to show the results of chemical analysis in present study.

Eight representative samples from Khair, Tappal, Nojhil, Pisawan, Hamidpur, Untasani, Bhagwangarhi and Adda were taken and plotted on bar graph, pattern, circular, vector diagram and trilinear diagram.

Bar Diagram:

In this diagram each analysis appears as a vertical bar having a height proportional to the total concentration of anions or cations expressed in milli equivalent per litre (epm). The left half of a bar represents cations and right half shows anions. These segments are divided horizontally to show concentrations of major ions group of closely related ions and identified by distinctive shading patterns. The vertical bar diagram (Fig. 6.8) reveals that at Khair among the cations, concentration of Ca is high

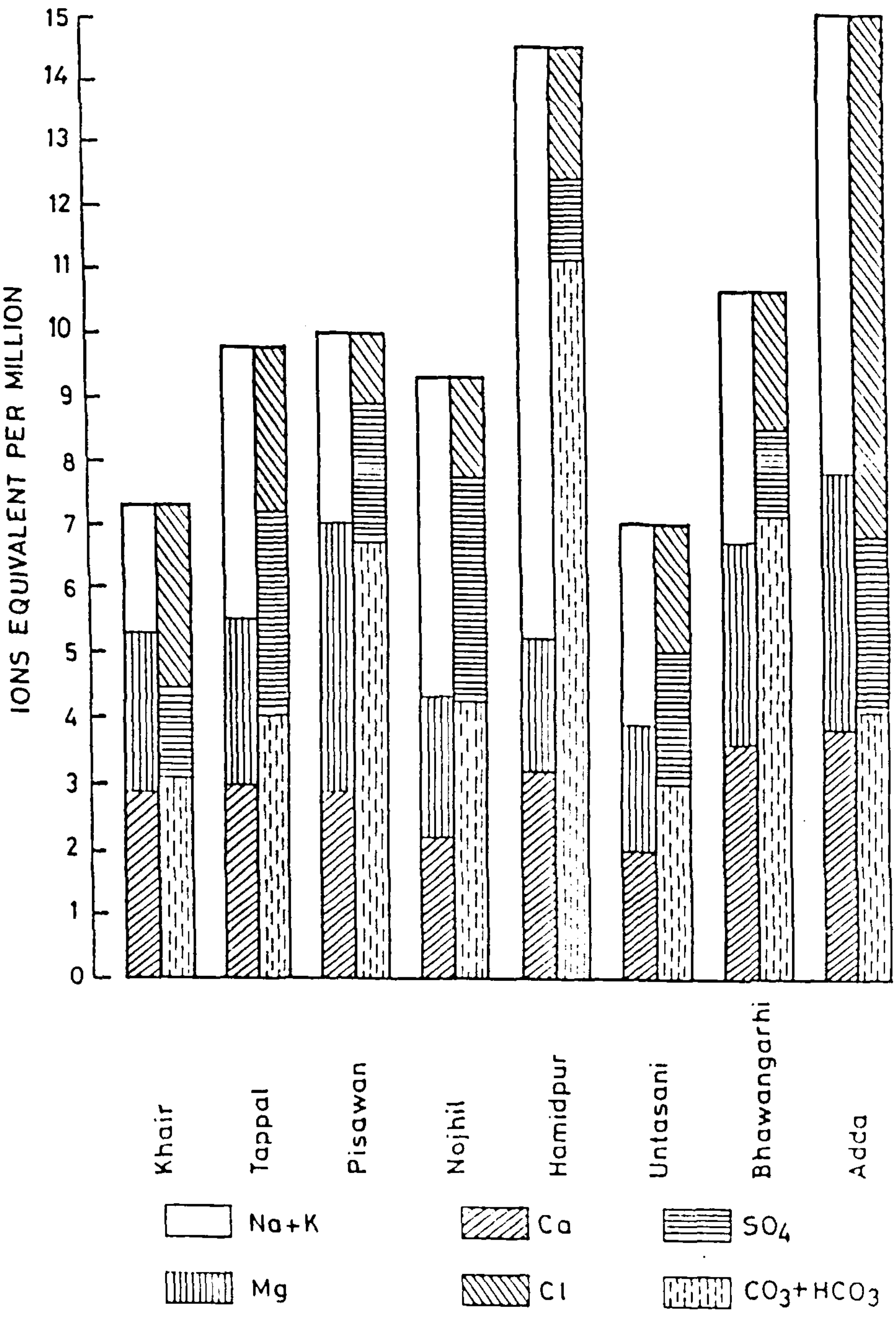


Fig. 6.8: Vertical Bar diagram of chemical analysis of representative water samples of the study area.

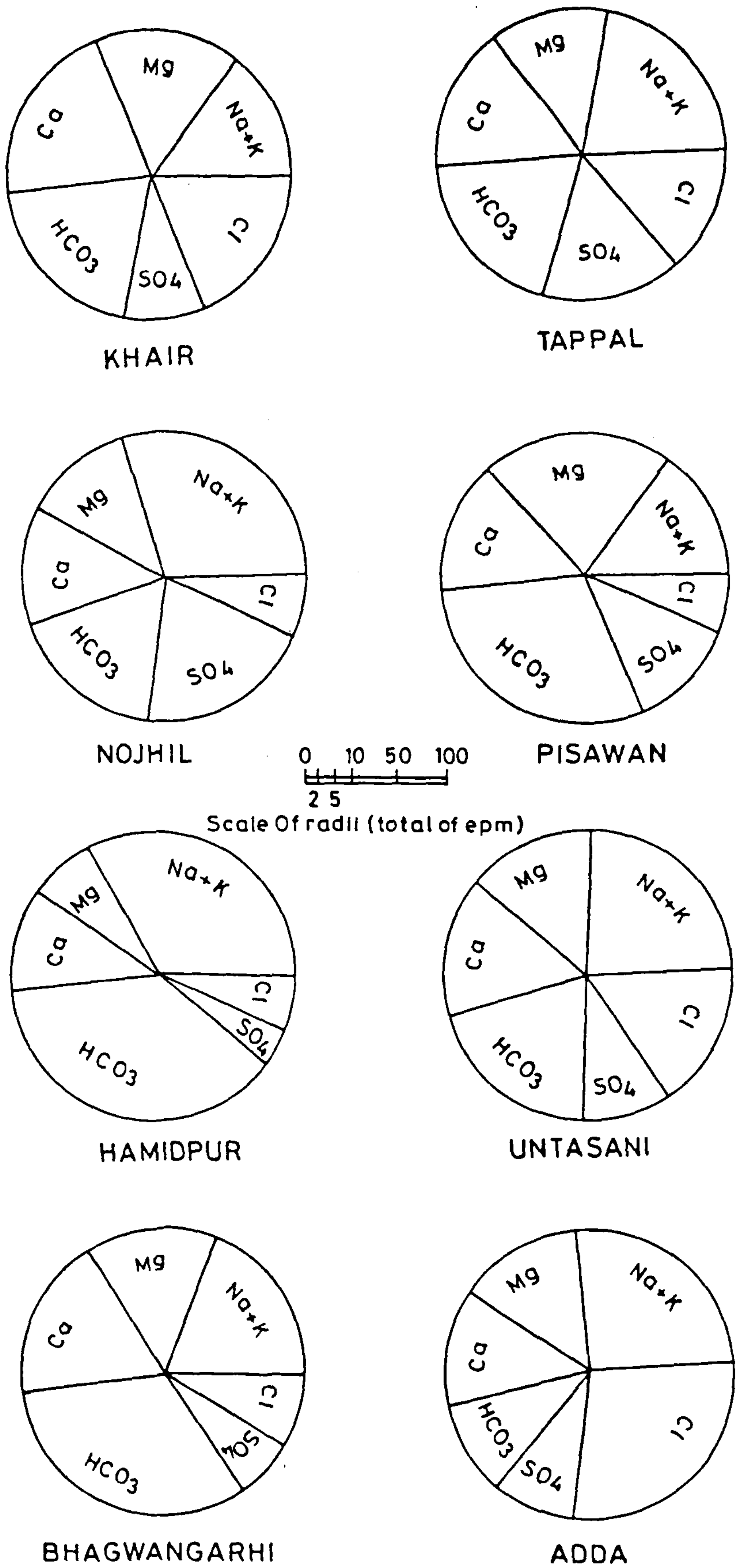


Fig. 6.9: Circular (Pie) diagram of representative samples at eight different places.

which is followed by the Mg. The concentration of Na + K is slightly low. Among the anions the concentrations of HCO_3 + CO_3^{--} and Cl^- are almost equal in proportions and SO_4 is comparatively low. the highest concentrations of anions and cations are found at Adda water sample. At Untasani the anions and cations are low in concentration than rest of the water samples which is possibly due to the dilution of the concentrations through flood water as the place is located on the active flood plain of the Yamuna river.

Further, the diagram reveals that concentration of Na + K is low in case of Khair than the calcium and magnesium while in all other samples Na + K is higher than the other constituents of cation group. Similarly, among the anions HCO_3^+ + CO_3^{--} is more than SO_4^{--} and Cl^- except at Adda. The concentration of CO_3^- + HCO_3^- and Cl^- is found higher at Hamidpur and Adda water samples respectively, possibly because they are located on uplands as where run off is more than the recharge or flushing/dilution of the dissolved constituents.

Circular Diagram:

The circular diagram (after Hem, 1970) of water quality is prepared according to a special scale for radii so that the area of a circle is proportional to the total ionic concentration of the analysis. Sectors within a circle show the fraction of the different ions expressed in milliquivalents per litre (Fig. 6.9).

Pattern Diagram:

Pattern diagram, first suggested by Stiff (1951) for representing chemical analysis by four parallel axes. The

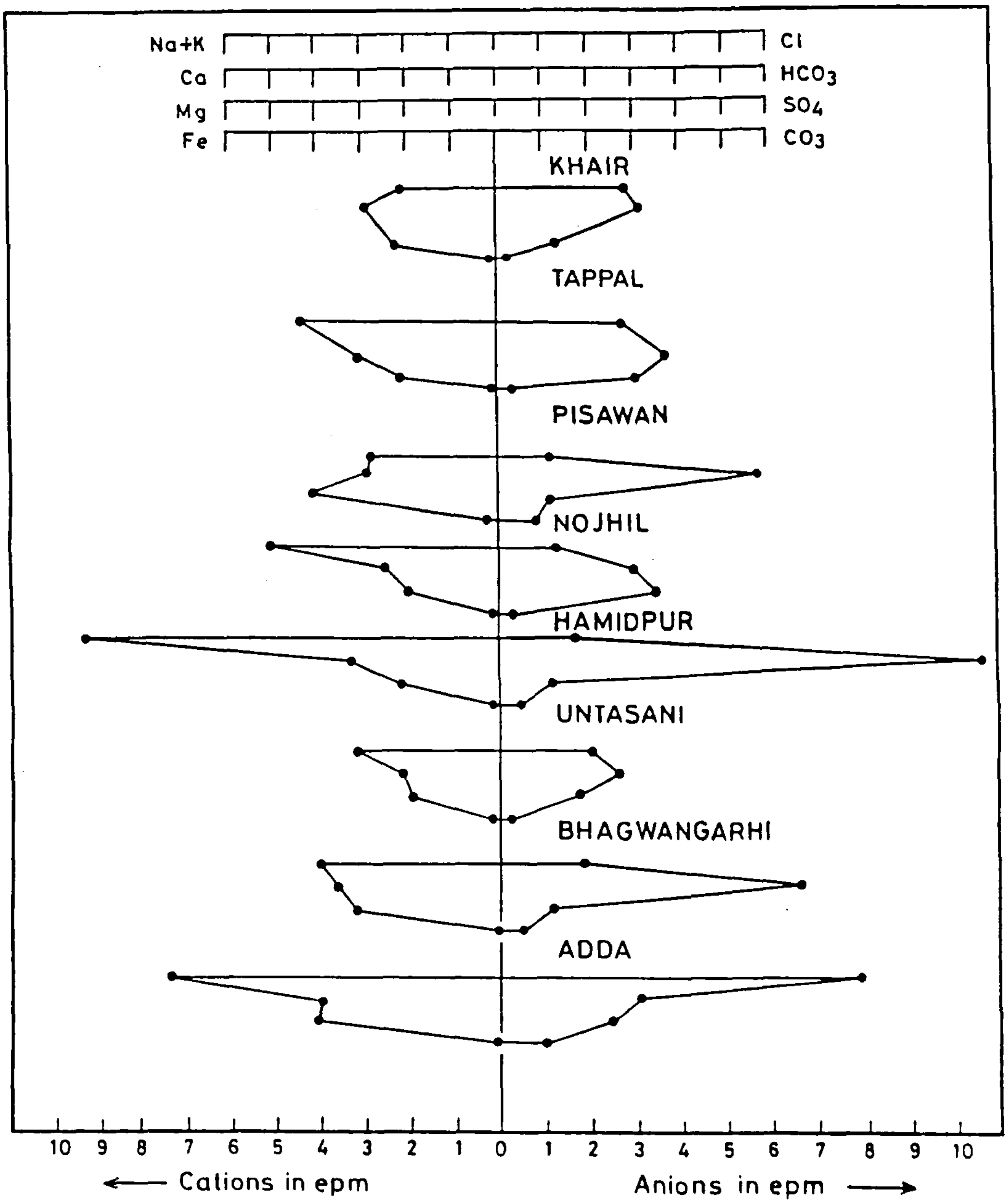


Fig. 6.10a: STIFF's Pattern diagram representing the analysis of groundwater quality at eight different places.

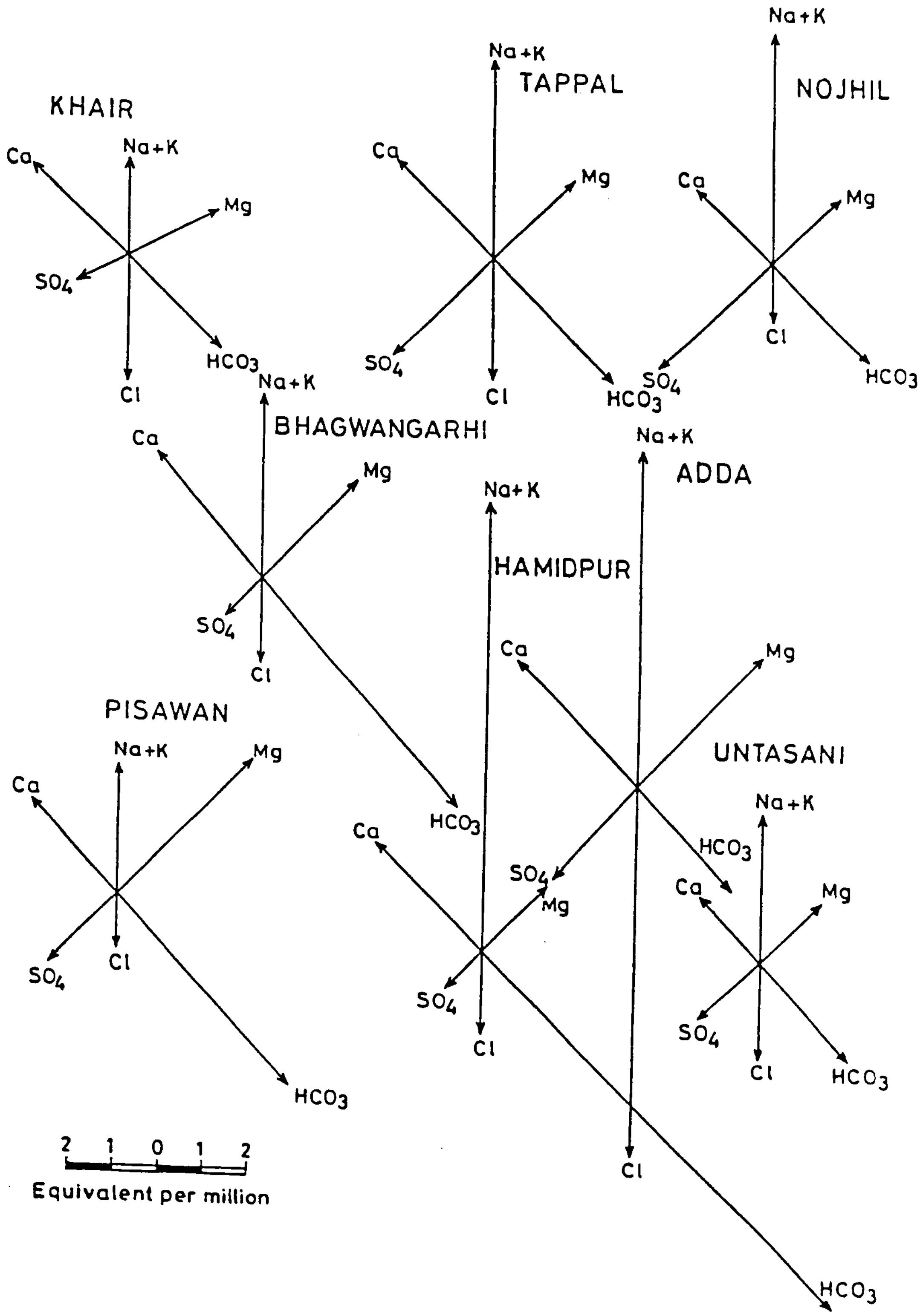


Fig. 6.10b: Vector diagram of representative samples.

concentration of cations are plotted to the left of a vertical axis and anions to the right all values are in milliequivalents per litre. The resulting points when connected form an irregular polygonal pattern. The analysis of the eight samples were plotted in pattern diagram (Fig. 6.10a). It too represents similar situation as evident from bar diagram.

Vector Diagram:

The vector diagram (after Hem, 1970) is an another method for plotting chemical quality with radiating vectors. The length of eight vectors represents ionic concentration in milliequivalent per litre as plotted in the diagram (Fig 6.10b). This diagram also shows the same pattern of groundwater quality of eight representative samples of the study area as in other graphs.

Trilinear Diagram:

Piper (1953) developed a form of trilinear diagram which is an effective tool in segregating analysis data for critical study with respect to sources of the dissolved constituents in groundwater; modification in character of a water as it passes through an area and related geochemical problems.

The piper trilinear diagram combined three distinct field for plotting, two triangular fields at lower left and lower right respectively, and an intervening diamond- shaped field. All three fields have scales reading 100 parts (Fig. 6.11). In the triangular field at the lower left, the percentage reacting values of the three cation groups (Ca^{++},

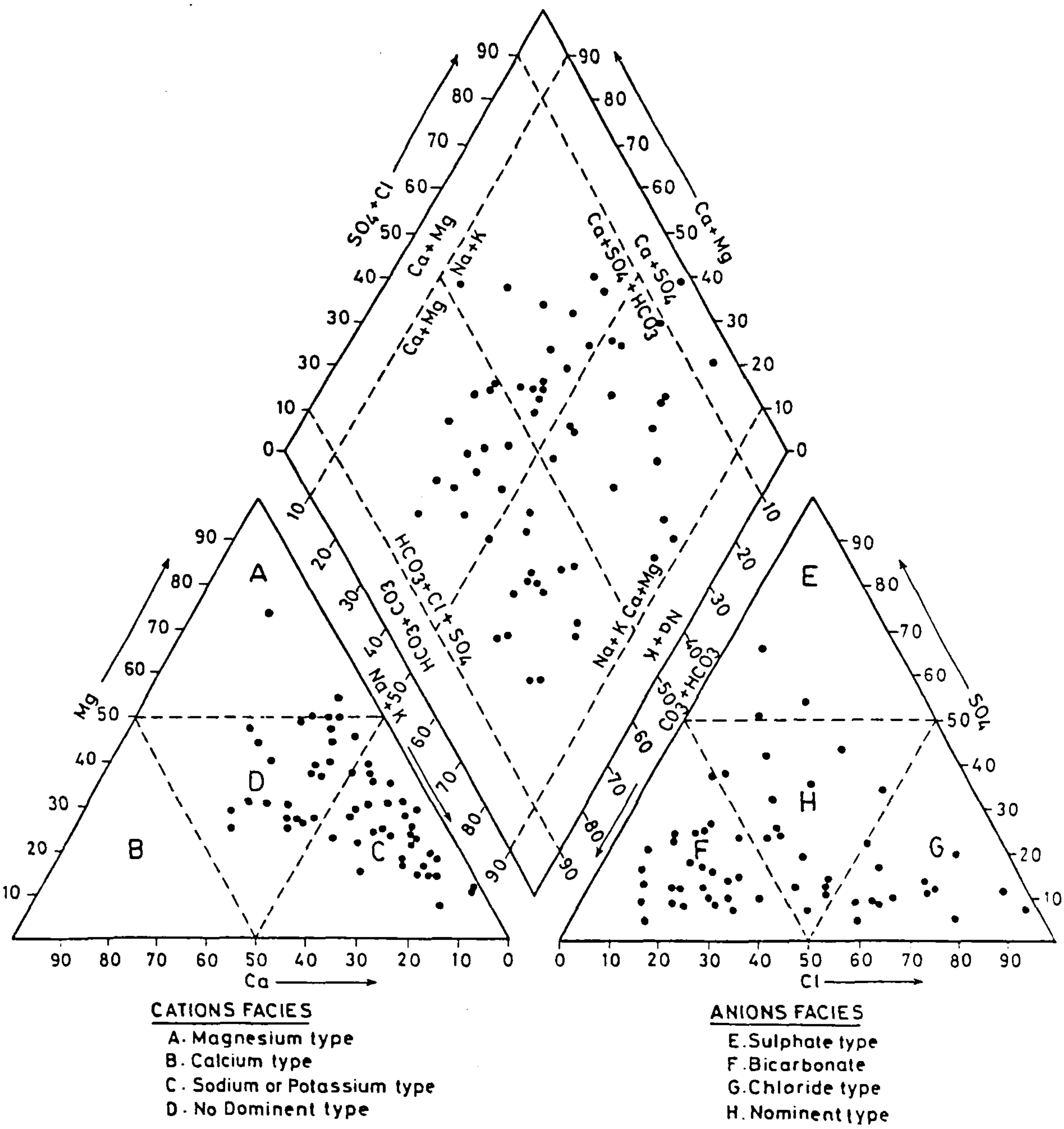


Fig. 6.11: Piper's Trilinear diagram showing chemical character of groundwater of the study area.

Mg^{++}, Na^{+}) are plotted as single point according to conventional trilinear coordinates. The three anions groups (HCO_3^-, SO_4^{--} and Cl^-) are plotted likewise at the lower right. Thus, two points on the diagram are in each of triangular fields indicate the relative concentrations of the several dissolved constituents of groundwater. The subtotal of all cations equivalents per million is taken as the 100 per cent base for computing percentages reacting values of the several cation variables, likewise for the several anion variables. The central-diamond shaped field is used to show the overall chemical character of the groundwater by single point plotting, which is at intersection of rays projected from the plottings of cations and anions. The position of this plotting indicates the relative composition of a groundwater in terms of cation-anion pairs that correspond to the four vertices of the field.

6.4 GROUNDWATER FACIES:

The concept of groundwater facies was developed by Back (1961, 1966); Morgan and Winner (1962) and Seaber (1962).

The definition of hydrochemical facies is a paraphase of the definition of facies as used by geologist; facies are identifiable parts of different nature, belonging to any genetically related body or system. Hydrochemical facies are distinct zone that have cation and anion concentrations describable within defined composition categories (Freeze and Cherry, 1979). As water flow through an aquifer it assumes a diagnostic chemical composition as a result of interaction with the lithologic framework or geologic environments. According to Back (1961) the term hydrochemical facies is used to describe the bodies of groundwater in an aquifer that differ in their chemical composition. The facies are a function of lithology, solution kinetics, and flow pattern of the aquifer (Back, 1966).

To designate hydrochemical facies of the study area, the cations and anions percentages have been determined. These values were plotted on the classification diagram (Fig. 6.11) for anion and cation facies as suggested by Morgan and Winner (1962) and Back (1966).

The plotting of the analytical data indicates that hydrochemical facies in the study area belong to mostly sodium or potassium type facies dominant among cations, with some samples which fall in the no-dominant type facies and only two samples, one from Kilpur and the other from Chinpari villages belong to magnesium class type. Among the anion facies, the majority of the samples fall in bicarbonate type facies and few samples belong to chloride and no-dominant type facies, while two samples from Sajnan and Dajyadpur villages belong to sulphate type facies. However, their corresponding intersections in the diamond-shaped field indicates that alkaline earths exceed alkalies in some samples and in other alkalies exceed alkaline earths.

The study of the diagram reveals that the ground-water quality of the study area belongs to alkalies with week acids Na-K-HCO_3 type and alkaline earth with week acids Ca-Mg-HCo_3 type.

6.5 WATER QUALITY CRITERIA IN RELATION TO ITS USE:

The term 'water quality' is a widely used expression which has an extremely broad spectrum of meanings. Since the desirable characteristics of water vary with its intended use, there is frequent unsatisfactory communication among the users of water as far as quality is concerned.

Furthermore, there is a worldwide increase in demand for good quality water. It has become imperative to protect and conserve the water not only as resource for their present uses but also for their prospective uses. The interpretation of a chemical, physical and biological analysis is highly subjective matter and is not possible to have a single criteria that can have universal application. Therefore, a certain accepted standard has been adopted while doing interpretation of chemical analysis results of water in relation to its use. The main classes of uses are:

1. Domestic
2. Irrigation
3. Industrial

6.5.1 Water Quality for Domestic Uses and Public Supply:

When setting permissible limits or ultimate goals for drinking water standards, cognisance must be taken of the bioaccumulation via the food chain; moreover, it is imperative to impose limits which not only protect man's health on the basis of trace metal quantities in water from which potable water is extracted. Drinking water standards are based on two criteries - (1) the presence of objectionable tastes, odours, or colours, and (2) the presence of substances with adverse physiological effects

Table 6.3: Range of concentration of various major and trace elements in shallow groundwater samples and their comparision with W.H.O. (1984) and I.S.I. (1983) Drinking water standards.

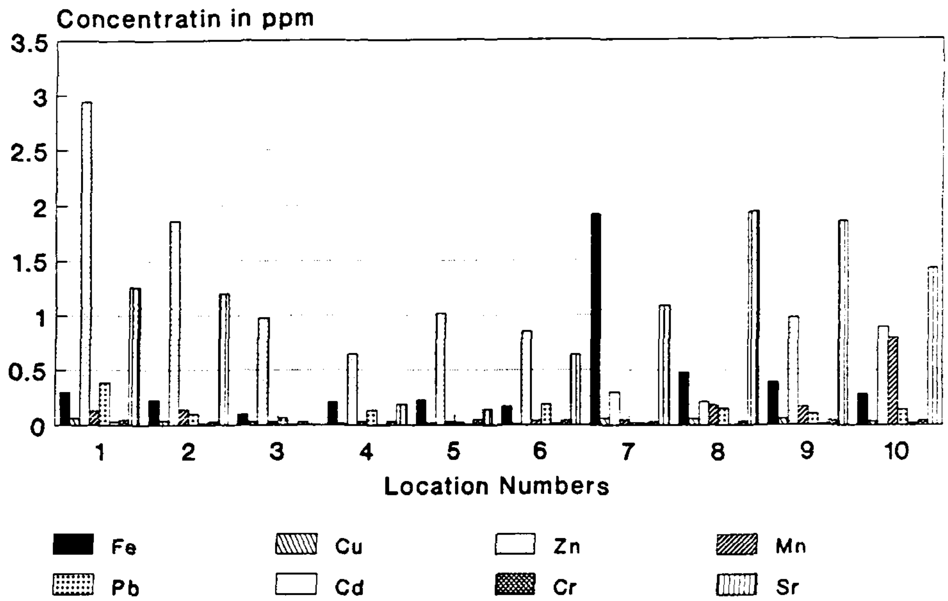
Constituents	World Health Organisation (1984)		Indian Standard Institute (1983)		Concentration in study area
	Highest desirable limit (mg/l)	Maximum permissible limit (mg/l)	Highest desirable limit (mg/l)	Maximum permissible limit (mg/l)	(Conc. in ppm)
pH	7-8.5	6.5-9.2	6.5-8.5	6.5-9.5	7.5 - 9.04
E.C.(in micro-mhos/cm at 25°C)	-	-	-	-	300 - 7200
Total Hardness	100	500	300	600	150 - 1020
Calcium	75	200	75	200	12 - 125
Magnesium	-	150	30	100	18 - 160
Fluoride	1.0	1.5	1.0	1.5	0.07 - 1.89
Chloride	200	600	250	1000	57 - 1230
Iron	0.1	1.0	0.3	1.0	0.04 - 2.681
Copper	0.05	1.5	0.05	1.5	0.012- 0.062
Manganese	0.05	0.5	0.1	0.5	0.029- 0.795
Zinc	5	15	5	15	0.981- 5.048
Cadmium	-	0.01	0.01	Norelaxation	0.002- 0.041
Lead	-	0.1	0.1	Norelaxation	0.025- 0.50
Chromium	-	-	0.05	Norelaxation	0.0298- 0.0486
Strontium	-	-	-	-	0.009- 1.941

(Word, Giger and McCarty, 1985). Various national and international organisations, viz., Indian Council of Medical Research (1975), Indian Standard Institution (1983), United State Public Health Association (1962), and World Health Organisation (1975, 1984) have laid down certain guidelines of water quality for domestic, municipal supplies and drinking purposes. The primary aim of these guidelines is to protect of public health and to combat the pollution hazards.

On the same criteria the concentration of various major and trace elements encountered in the water samples of the study area is compared with drinking water standards of the World Health Organisation (1984), Indian Council of Medical Research (1975) and Indian Standard Institute (1983), which are given in Table 6.3.

The Table 6.3, Appendix-XA and earlier discussion show that the concentration of Total Dissolved Solids, Ca, Mg, Cl, Na, K, F and SO_4 are within the permissible limits of W.H.O. (1984) and I.C.M.R. (1975) in most of the places of study area. Although E.C. is found higher in most of the places. Generally, the water is hard and alkaline all over the study area. Astringent taste and objectionable odour is found at Edalgarhi, Mirpur, Naoli and at some villages in central part of the area. Overall the groundwater is fresh and slightly brakish at places hence the concentration of major elements cannot cause any hazard in drinking water of the areas.

However, the concentration of certain trace elements (Table 6.3 and Fig. 6.12) like Fe, Cr, Pb and Cd has been reported higher than their prescribed limits in



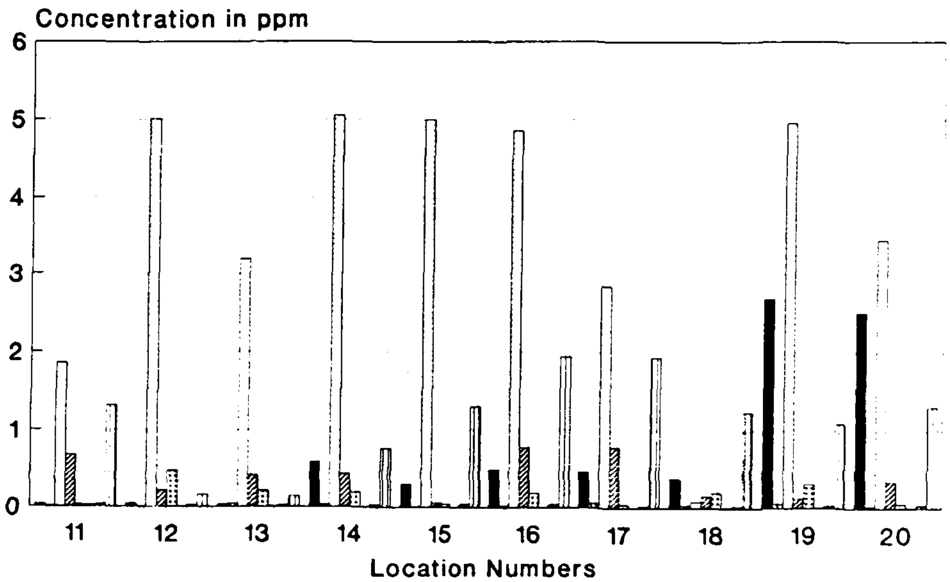
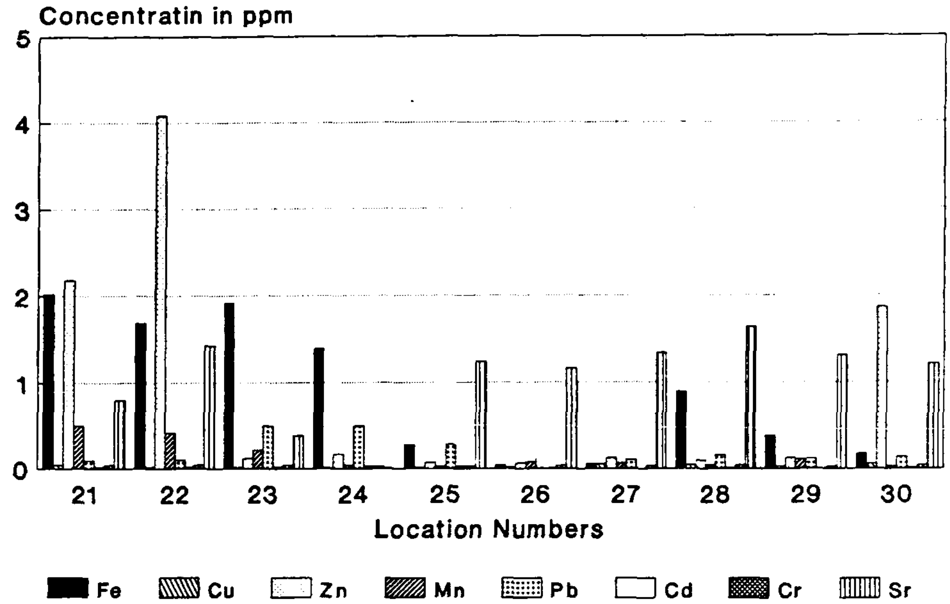


Fig. 6.12: Showing the Concentration of Trace Elements in the groundwater of the Study Area



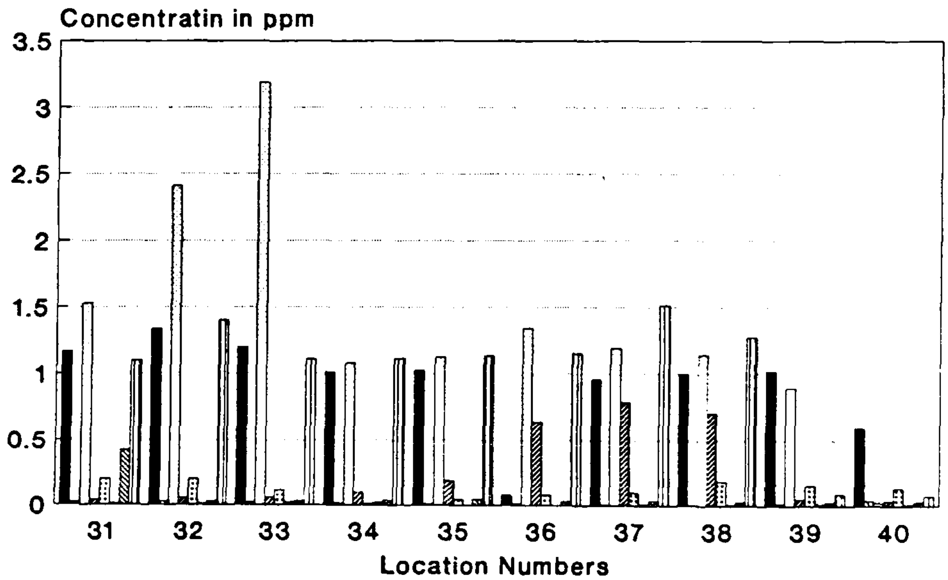


Fig. 6.12: Showing the Concentration of Trace Elements in the ground water of the study area

drinking water at some places. These trace elements are probably most harmful and toxic pollutants because of their biological, non-biodegradable nature and their potential to cause adverse effects in human being at certain level of exposure and absorption. the harmful effects are linked to the accumulation in biological system even in their lowest form of development. Many workers have studied the quality of drinking water in relation to trace elements (Carm and McCabe, 1975; Neri et al., 1975; Olwin, 1977; Schroeder and Kramer, 1974).

These studies have indicated an association between water quality and mortality from cardiovascular and other chronic diseases. A significant positive correlation between mortality from various types of cancer and the concentration of trace metals in water supplies has also been described (Berg and Burbank, 1972; Sunderman, 1977). The water supply system is a major source of metals in drinking water (Carm and McCabe, 1975). Corrosion of distribution system and the household plumbing also add to metal content of drinking water.

Various trace elements determined in the groundwater samples of study area in relation to drinking purposes and their various health hazards are discussed in an earlier paragraphs of this chapter. The places where the concentrations of Pb, Fe, Cd and Cr are found higher need speical and immediate attention to check the poisoning of these elements.

6.5.2 WATER QUALITY CRITERIA FOR IRRIGATION:

The suitability of a groundwater for irrigation is contingent upon the effects of the mineral constituents of the water on both the plant and the soil. The quality of suitable irrigation water is very much influenced by the constituents of the soil which is to be irrigated. Hence, water quality criteria for the irrigation purposes is a complex subject, as growth of a particular crop depends on many factors and not merely on chemistry of irrigation water. However, chemical quality of water is an important factor to evaluate the suitability of water for irrigation (Gupta, 1989).

Factors to be considered in evaluating the usefuleness of groundwater for irrigation are - the total concentration of individual constituents, the nature and composition of the soil and subsoil, the topography of the land, the position of the water table, the volume of the groundwater used and the method of applying it, the kinds of crops grown, the climate of the area, the method of the crop management, and local drainage conditions (Walton, 1970).

Irrigational Specification:

Various specifications have been proposed from time to time by different workers including Asgar et. al. (1936); Kellay et al. (1940); Wilcox (1955); Eaton (1950); U.S. Salinity Laboratory Staff (1954); Saligram (1961); Uppal (1964); Federal Water Pollution Control Authority (1968); Environmental Protection Agency (1973); Ayers and Branson (1975) and Ayers and Wastcot (1976) for evaluating the suitability of natural water for irrigation of crops.

In order to study the suitability of groundwater in the Yamuna-Karwan sub-basin for agricultural uses, the

Electrical Conductivity, relative proportion of sodium to other cations, residual carbonate and concentration of certain specific elements were analysed and the data obtained from the chemical analysis of groundwater samples were processed and interpreted in the established guidelines proposed by various scientists and organisations (Appendix - IXA).

Salinity and Sodium Hazards:

Irrigation water is one of the major contributors of soluble salts to the soil in addition to those already present. Salts of Ca, Mg, Na and K present in the irrigation water, may prove injurious to plants. When present in excessive quantities, they reduce the osmotic activities of the plants and may prevent adequate aeration, causing injuries to plant growth depends upon the concentration of salt in the soil. In shallow water table area where groundwater is saline, the evapotranspiration process also creates a suction force that may produce an appreciable upward flow of water and salts to the root zone by which many types of soils become salinized and the water-soil salinity become so high as to retard the germination of seed or growth of plants.

The total dissolved solids content, measured in term of specific electrical conductance, gives the salinity hazards. Excessive sodium content in water renders it unsuitable for soils which in exchange gives up Ca^{++} & Mg^{++}. This base action altered the physical characteristics of soils. If the irrigation water contains Ca^{++} and Mg^{++} ions in quantity that equals or exceeds the quantity of Na^{+} and sufficient concentration of Ca^{++} and Mg^{++} will be retained on the clay particles of the soil to maintain good tilth and permeability. Such water is good for irrigation even though the total mineral contents may be quite high.

In place of rigid limits of salinity for irrigation water, quality is expressed by classes of relative suitability. Wilcox (1955) prepared a classification on the Electrical Conductivity, per cent sodium and boron concentration for irrigation water. the sodium per cent is calculated by the following formula given by Todd (1980).

$$\text{Sodium per cent} = \frac{(Na + K)\ 100}{Ca + Mg + Na + K}$$

where all the concentrations are expressed in epm. The following classification is given by Wilcox (1955).

Table 6.4: Quality classification of water for irrigation

Water	Na %	EC mhos/cm
Excellent	20	250
Good	20 - 40	250 - 270
Permissible	40 - 60	270 - 2000
Doubtful	60 - 80	2000 - 3000
Unsuitable	80	3000

The obtained results is compared and plotted on Wilcox diagram (Fig. 6.13, Appendix - IXA). The diagram reveals that about 50 per cent of the water samples fall in excellent to good and good to permissible classes, other 25 per cent falls in permissible to doubtful class and rest

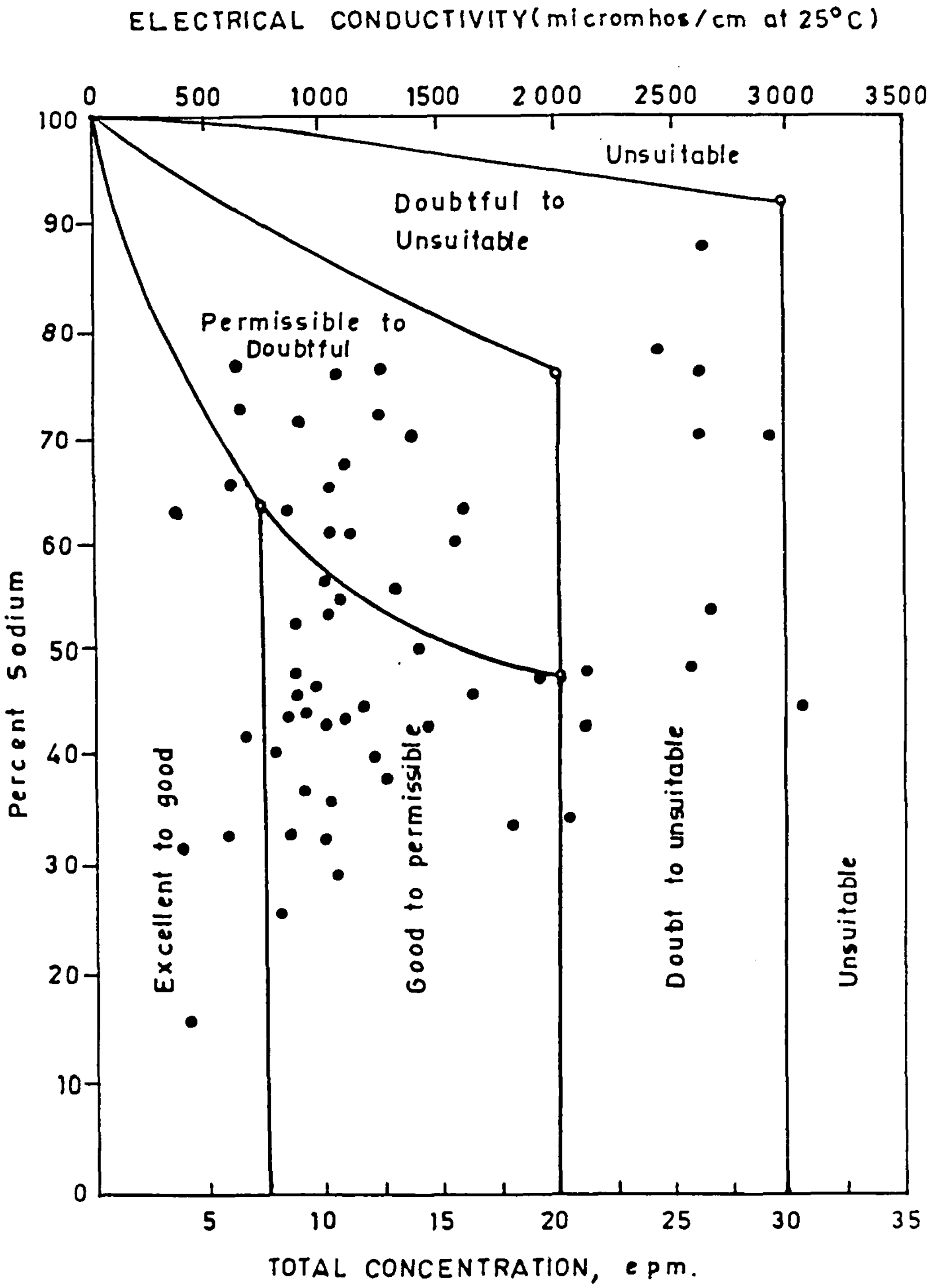


Fig. 6.13: Showing plots of sodium percent against E.C. values (After Wilcox).

fall in doubtful to unsuitable while one sample from Jattari village falls in unsuitable class. Hence the groundwater quality of the study area is not uniform.

U.S. Salinity Diagram:

The interpretation of water quality suitable for irrigation purposes is given by Richard et al. (1954) of U.S. Salinity Laboratory (U.S.S.L.). They put forward a diagram on the salinity of water. electrical conductivity has been taken as an index of salinity hazards and Sodium Adsorption Ration (SAR) as an index of sodium hazards. The SAR is defined as:-

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

where concentration of cations are expressed in meq/litre.

The quality of classification is given in the Table 6.5.

Table 6.5: Quality classification of irrigation water (after U.S.S.L., 1954)

Salinity Hazards (E.C. in micro-mhos/cm at 25°C	Alakali Hazards S.A.R.	Water class	R.S.C.* in meq/l
250 (C_1)	10 (S_1)	Excellent	1.25
250-750 (C_2)	10-18 (S_2)	Good	1.25
750-2250 (C_3)	18-26 (S_3)	Moderate	1.25-2.5
2250 (C_4)	26 (S_4)	Poor	2.5

*Residual Sodium Carbonate

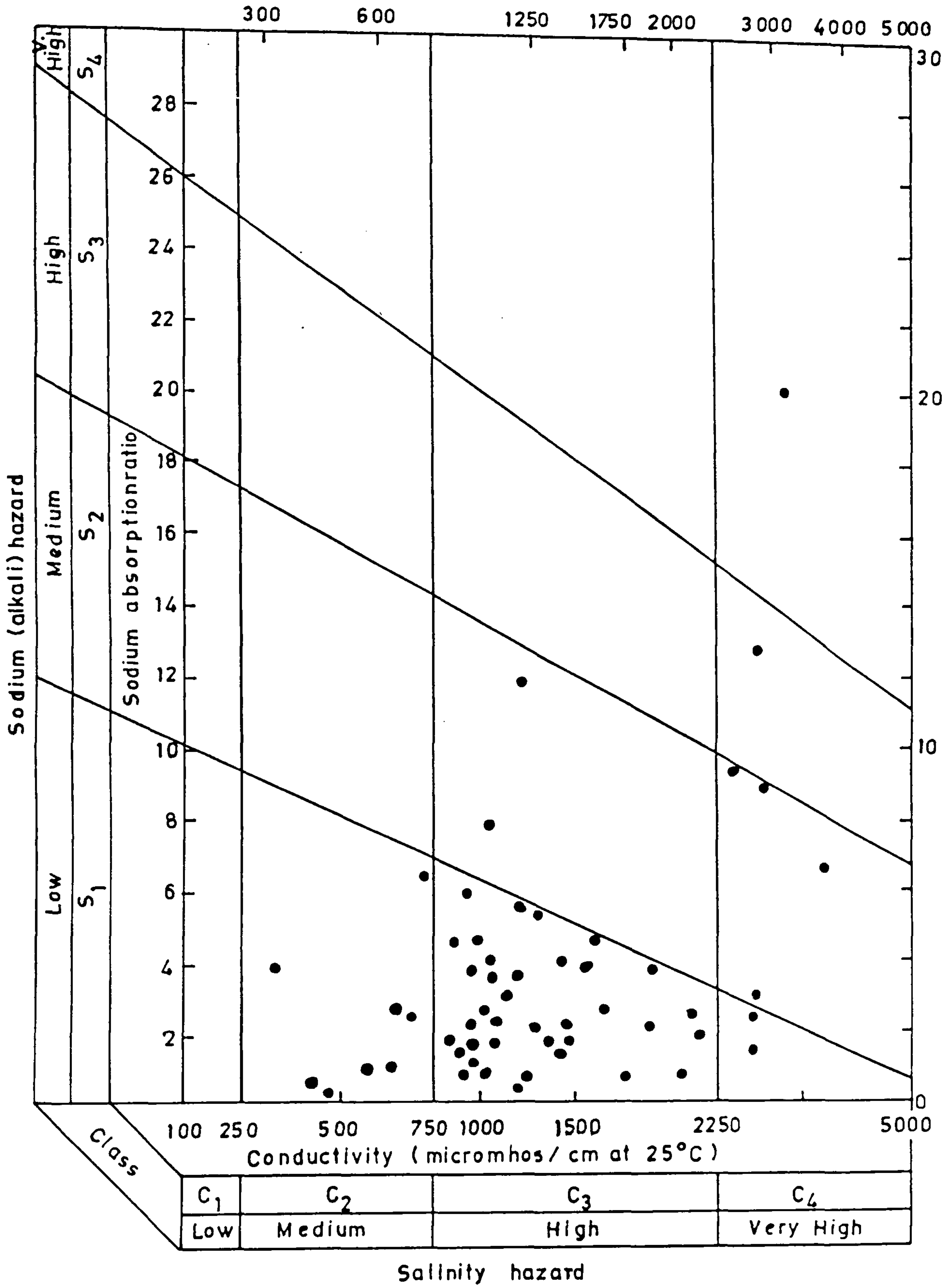


fig. 6.14: Showing plots of SAR values against E.C. values (U.S. Salinity Laboratory diagram).

The SAR have been calculated and the data obtained is compared and plotted on the U.S.S.L. (1954) diagram, (Fig. 6.14). The diagram gives direct indication of the salinity and alkalinity hazards. From the diagram (Fig. 6.14), it is found that the water quality of the study area belongs to C_3S_1 and C_2S_1 classes i.e. within the zone of good to moderate water quality in most of the area while few samples falls within the C_3S_2 and C_4S_2 classes and one sample falls in C_4S_3 class. Only one sample from Jattari observation well falls in C_4S_4 (poor zone) class. In general, the quality of groundwater in shallow aquifers is not uniform.

Eaton (1950) suggested that water having carbonate and bicarbonate ions in excess of Ca + Mg will lead to much greater alkali formation than is indicated by its SAR and thereby decreasing soil permeability. The carbonate and bicarbonate hazards on water quality can be determined in terms of Residual Sodium Carbonate (RSC), which is defined in the following equation:

$$RSC = (CO_3^{--} + HCO_3^{--}) - (Ca^{++} + Mg^{++})$$

where all the concentrations are expressed in epm. Water with RSC below 1.25 meq/l is good, 1.25-2.5 meq/l is marginal and above 2.5 meq/l is not suitable for irrigation purposes.

The residual sodium carbonate of water samples have been determined and the results obtained are given in (Appendix-IXB). A perusal of Appendix shows that in most of the samples the RSC is less than one and on between 1.25-2.5 meq/l but at few places higher values have also

Table 6.6: Trace elements tolerance limit of irrigation water as proposed by FWPCF (1968) and Ayers and Branson (1975)

	Water use (FWPCF, 1968)		Water use (Ayers, Branson, 1975)	
	Continuous	Short term in fine textured soils	Continuous	Short term in fine textured soils
Copper	0.20	5.0	0.20	5.0
Iron	-	-	5.00	15.0
Manganese	2.00	5.00	0.20	10.0
Zinc	5.0	10.0	2.00	10.0
Cadmium	0.005	0.05	0.01	0.05
Lead	5.00	10.0	5.00	10.0
Chromium	5.00	0.05	0.10	1.0
Lithium	5.0	5.00	2.5	2.5

been determined. By and large the groundwater is suitable for irrigation in terms of RSC too.

Trace Elements:

Apart from the major ions, trace elements like Cu, Pb, Zn, Fe, Mn, etc. were determined. Federal Water Pollution Control Federation, U.S.A. (1968) and Ayers and Branson (1975) put forward tolerance limit for irrigation water.

On comparison of analytical data of water samples of study area with standard limits proposed by F.W.P.C.F. (1968) and Ayers and Branson (1975) (Table 6.6), it is found that trace elements in the groundwater of the area are well within the permissible limits and as such they will not produce any effect on plants if water is used continuously for irrigation purpose.

6.5.3 WATER QUALITY FOR INDUSTRIAL USE:

Chemical quality criteria for industrial uses varies widely. The pure waters are required for the manufacture of paper, beaverages, confectionary, ice-making and pharmaceuticals. The 80 per cent of industrial water is used for cooling and need not be of high quality as otherwise hard water will cause encrustations on the inside of the boilers, thus offering resistance to heat transfer. In certain cases, the industrial water must have lower contents of dissolved salts than what is permitted in drinking water. The presence of sodium is generally useful as it makes them soft.

As a result, an adequate groundwater supply of suitable quality has become one of the primary considerations in selecting new industrial plant locations. As there is no major industry located in the study area except few cottage and small industries. In the view of the facts discussed, the water quality of the area can be recommended for industrial purposes. Where the water is found hard, it can only be used after proper treatment.

6.6 SURFACE WATER QUALITY:

In order to study the surface water quality the water samples were collected from different sampling stations established on the rivers Yamuna, Karwan Nadi, Patwah nala, Mat branch (canal) etc. in the study area. The samples were collected from upstream, midstream, and downstream points of the rivers and canal in the study area so as to know the variation of concentrations at different places. Samples were analysed and the data obtained are appended as Appendix-XII-A & XII-B.

Table 6.7 shows the comparison of various constituents in the Yamuna and Karwan rivers and Mat canal waters with W.H.O. (1984) and I.S.I. (1983) drinking water standards. A perusal of table shows that pH ranges from 7.5 to 8.2, 6 to 8.8, 6.9 to 8.4 and 7.1 to 8.9 in the water samples of rivers Yamuna and Karwan, Patwah nala and Mat canal, respectively. The E.C. varies between 175 to 350, 410 to 853, 642 to 985 and 285 to 778 micro-mhos/cm at 25°C respectively in water samples of above localities. These values show the alkaline nature of these water. Further, the results of the chemical analysis reveal that the values of cations and anions are low in Yamuna and Karwan rivers,

Table 6.7: Range of concentration of various major and trace elements in surface water samples and their comparison with W.H.O. (1984) and I.S.I. (1983) drinking water standards

Constituents	World Health Organisation (1984)		Indian Standard Institute (1983)		Range of cencentration in surface water bodies (in ppm)			
	Highest desired limit mg/l	Maximum permissible limit mg/l	Highest desired limit mg/l	Maximum permissible limit mg/l	River Yamuna	River Karwan	Mat Canal	Patwah Nala
pH	7-8.5	6.5-9.2	6.5-8.5	6.5-9.2	7.5-8.2	6-8.8	7.1-8.9	6.9-8.4
E.c.(micro mhos/ cm at 25°C)	-	-	-	-	175-350	410-853	285-778	642-985
Calcium	75	200	75	200	21 -30	38-58	31.18-40.0	62-110
Magnesium	-	150	30	100	8 -15	21-28	10.0-16.30	44-70
Total Hardness	100	500	300	600	85 -115	205-213	110-140	280-310
Chloride	200	600	250	1000	10-20	20-45	31.61-44.10	35-60
Iron	0.1	1.0	0.3	1.0	0.85-1.68	0.96-1.82	0.546-0.930	0.75-1.04
Ccpper	0.05	1.5	0.05	1.5	1.03-1.89	1.74-2.04	0.295-0.386	2.08-2.68
Manganese	0.05	0.5	0.1	0.5	0.348-0.780	0.586-0.804	0.024-0.095	0.453-0.904
Cadmium	-	0.01	0.01	Norelaxation	0.02 -0.06	0.03 -0.09	0.006-0.014	0.02 - 0.08
Lead	-	0.01	0.01	"	0.148-0.188	0.193-0.275	0.05-0.09	0.160-0.359
Zinc	-	0.01	0.01	15	6.61 -16.10	13.04-18.04	4.06-8.15	11.23-14.83
Chromium	-	-	0.05	Norelaxation	0.039-0.045	0.034-0.058	0.03-0.07	0.034-0.061

but in water samples of Mat canal, it is higher in two samples. The Karwan river water shows higher values of cations and anions than the Yamuna river water samples. However, all the surface water samples show low concentration of cations and anions than the groundwater samples of the study area.

The analytical results show that the concentration of certain trace elements like Fe, Mn, Cd, Pb, Cr^{+6}, and Zn are higher than their permissible limit for drinking purposes in water samples of rivers Yamuna, Karwan and Patwah nala.

As a result, these waters are, however, suitable for irrigation uses. As regard higher values of toxic trace metals it can be said that it is caused due to the municipal, industrial and untreated sewage into these rivers.

6.7 ENVIRONMENTAL HAZARDS:

The major environmental problems which may cause adverse effects on the ecosystem, are soil alkalisation, salinity of groundwater, water-logging along canals and geomorphic depressions with seasonal water-logging in low lying areas.

Soil Alkalisation:

Salinity is one of the major land degradation process that restrict the economic, agricultural and efficient utilization of soil and land resources. The rise of salt to the surface through the process of capillary action due to the evapotranspiration in the areas of shallow water table zones is mainly responsible to soil alkalinisation. These type of areas are generally, located near canals.

In order to delineate the alkali soil area, visual interpretation of satellite imagery were used for the purpose at Indian Institute of Remote Sensing, Dehradun (Fig. 6.15). Such tracts were observed at places of Kahir, Tappal and Nojhil blocks.

The reclamation of such soil is generally carried through surface treatment by applying pyrite and gypsum rich fertilizers. Soil scientists have recommended plantations of certain varieties of trees and grasses which are resistant to soil alkalinisation. In addition to this, the canals should be properly aligned away from the shallow water table areas along with the lining of the canals is suggested to check the seepage.

Besides, the alkali soils the areas affected with saline or brakish water has been reported in wells. At places, in such areas also include some wells which yield potable water. The salinity of the groundwater may be due to tne salts present in soil, dissolved by rain water and carried down in solution. The synchronous variation in the specific conductivity of some of the well waters is very suggestive of a situation that leads to concentration of dissolved ions. Saline water areas were found at some places in Khair, Tappal, and Nojhil blocks as shown in the map.

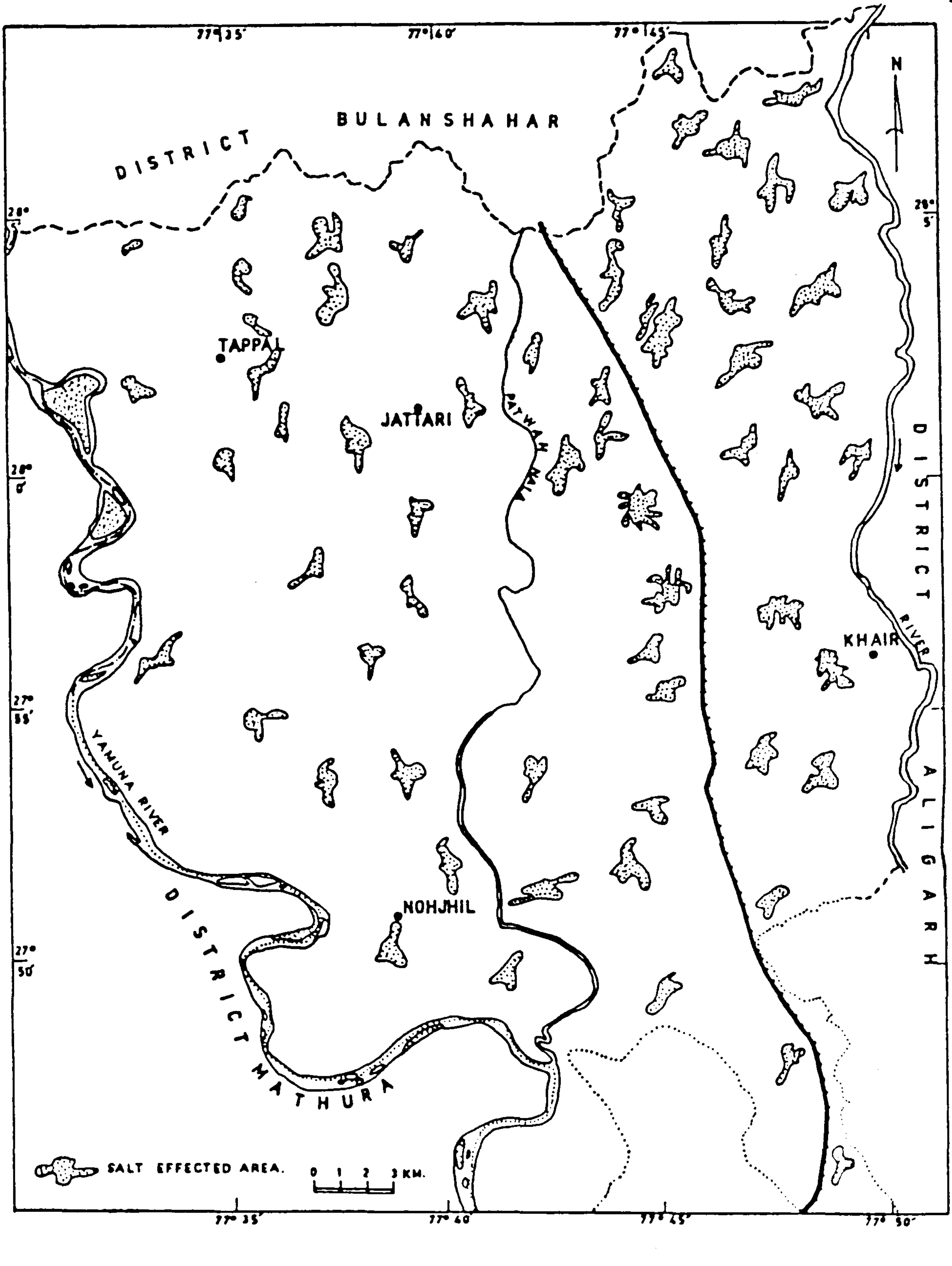


Fig. 6.15: Showing the salt affected areas in the study area.

Water Logging:

The area under study is occupied by only Aligarh-Mathura surface which is the oldest and highest landform and is free from the flood water but there are geomorphic depressions in which the rain water accumulates and the problem of water logging is common. A large part of area around Nojhil and Khair blocks gets inundated by the flood waters brought by Yamuna and Karwan rivers during monsoon, making the area seasonally water logged for a short period.

Besides, the unlined Mat canal, the small water bodies and ponds, paleo-channels and cut-off meanders also contribute water-logging problems in the study area.

The water-logging conditions adversely affect the roads, the building, the water supply and drainage system and even the crops. Vast tracts of land have become unfit for agricultural purposes due to the salt encrustations on the surface and most of the land has become marshy. Thus making it uncultivable (shown in Plate-IV, Chapter II). Such areas can be found near Parsauli, Kilpur, and Naoli villages. To combat this water logging phenomenon, the following recommendations are made - (i) Construction of surface drains, (ii) Lining of canals and other water courses, (iii) Construction of discharge tubewells, (iv) Change in cropping pattern, (v) Tree plantation and (vi) Curtailing of canal discharge during non-irrigational periods.

Human Interference:

Some of the environmental problems can be attributed to human interference in nature such as modification of land, etc.

The agricultural practices over the sand dunes and their irrigation turn these mounds into flat terrain. Though more and more interdunal area of fertile land is covered with sand but in turn it helps in making these dunes more and more subduned. Presently, this process seems to engulf the fertile land by sand migration but in the long run it converts the land into cultivable terrain.

The intricate network of unlined canals make more and more area along them water logged which renders the land uncultivable. The excess use of fertilizers, and pesticides in agriculture make the surface and groundwater polluted. The human interference does not end here but with the rapid expansion of urbanisation and industrialisation make the more and more areas unsuitable for a favourable environment.

SUMMARY & CONCLUSION

SUMMARY AND CONCLUSION

Water is prime natural resource which governs life on the earth and also influences economic, industrial and agricultural growth of mankind. India has made tremendous progress since independence but still the country has a long way to go in the development of her water resources. In all, India has 113 million hectare meter (mham) of water resources of which 45.23 mham. is groundwater. India will touch a billion mark population by the turn of the century and will need then about 240 m tons of food grains. To meet this growing needs of food and fibre for ever increasing population, besides, agriculture, industrial and domestic water demand for the integrated development, it becomes an essential pre-requisite to evaluate the groundwater resources afresh. The present investigation is an attempt in this direction.

Accordingly, the study was carried out in order to delineate the regional aquifer systems, their geometry, quantum of water resources and their quality in parts of Yamuna-Karwan sub-basin of the Ganga-Yamuna Doab. The area spreading over 1033 sq. kms., forms a part of the Central Ganga basin. The Yamuna and Karwan rivers, respectively form the western and eastern hydro-boundaries.

Physiographically, the area is a gently sloping plain due south to south east with a gradient of 0.26 m/km. Geomorphologically, the area is classified into three main geomorphic units based on the criteria of relief, lithology, soil, vegetation, drainage and land use pattern. Which are; (i) Eolian sand surface, (ii) Yamuna Alluvial plain and (iii) Yamuna flood plain. The area is drained by the Yamuna and Karwan rivers which flow due south. The Yamuna affects only the strip of Khadir (low valleys) lying below the old high bank while the Karwan river has a broad basin with low lands on both sides which finally joins the river Yamuna on the down stream side near Agra.

The study area falls under the sub-tropical climatic zone and experiences extremely hot summer (40-45°C) with strong westerly hot winds and chilly winters (4-9°C). The monsoon breaks up by the 2nd week of June and lasts till the end of September. The mean annual rainfall is 693.74 mm. About 90% of the total rainfall occurs in the months of July and August each year. The coefficient of rainfall variation varies from 32.22 to 43.34% with an average of 37.78% which indicates a significant variability of rainfall in time and space. There is recurrence of mild to normal drought with every decade.

Three major soil types namely (i) sandy loam, (ii) clay to clayey loam and (iii) loam to sandy loam were observed. The total irrigated area out of 83.33% of the cultivation area is about 85,332.71 hectares. The Mat branch feeder canal and its networks, shallow and deep tubwells form the main source of irrigation. 82.99% of the area is irrigated through groundwater and 16.82% through the surface water sources.

The Ganga basin is the largest repository of groundwater in India. As regards its origin various views are there. That it was formed as a result of sagging of earth crust that intervened between mobile belt of the Himalayas and comparatively stable Peninsular shield which was latter filled up with the sediments eroded from newly risen

Himalayas and the Peninsula. Another view considers it a peripheral foreland basin formed as a result of continent-continent collision between Indian and Asian plates.

The exploratory drilling operations carried out during the past three decades for the search of oil and groundwater by the O.N.G.C. and the Central Groundwater Boad have revealed the sub-surface topography consisting of alternate spurs and depressions. Geologically, the Bundelkhand granite complex forms the basement. The basement complex underwent block faulting generating thereby a central horst and two grabens designated as East and West U.P. Shelves. On the eroded surface of this basement the Upper Vindhyans were deposited probably during the Upper Proterozoic era. Thereafter, it underwent post-Vindhyan faulting and erosion since Cambrian to lower Miocene. During this long span of time (encompassing about 500 million years), the Vindhyan topography was reduced to almost peneplain and on these eroded surface Neogene Siwaliks were deposited which was latter on followed by the deposition of Quarternary alluvium. This Quarternary deposits healed up the earlier depressions through rapid sedimentation giving thereby a broad monotonous level expanses which is the present Ganga basin. Further, the thickness of the Quarternary sediments increases due north and attains the maximum thickness close to the Himalayan foothills.

The river Yamuna has given rise to number of sand bodies such as channel, flood plain and backswamp deposits, generating thereby various aquifer types during the past 10,000 years. The fence diagram and the various hydrogeological cross-sections distinctly depict two to three tier aquifer systems down to the depth of 92 metre b.g.l. These aquifers finally merge with each other and behave as a single bodied aquifer system. Alluvium with its sizeable thickness comprises clay, silt and sands of various grades, occasionally intermixed with gravel and kankar in varying proportions. The beds are generally lenticular and there are rapid alternation and gradations between granular and clayey materials particularly in NW and SE parts of the area. The granular zone attains its maximum thickness in the eastern part of the area which gradually decreases due west. The groundwater of the area occurs under water table condition in shallow and semi-confined to confined condition in the deeper aquifers. The shallow and deeper aquifers are separated by thick clay layer intermixed with kankar which behaves as an aquitard.

A perusal of pre-monsoon (1992-93) depth to water maps reveal that in western part, water level is generally deep and ranges between 8 to 19 meters b.g.l. The shallow water level leading to swampy conditions during post-monsoon period (Nov. 1992-93) was observed as a characteristic feature of low lying areas adjacent to the Mat branch feeder canal. In these tracts, the water level during (June 1992-93) ranges between less than 2 to 6 meters b.g.l., which shows the resultant effect of the quantum of seepage of water through the unlined canal beds.

The water level fluctuation maps reveal that in a major part of the area the fluctuation ranges between 0.5 to 1.0 meter and is followed by the zone showing fluctuation in the range of 1.0 to 1.5 m. The fluctuation map of 1993 does not show any significant change in water level which may be attributed to the scanty rainfall during the year 1993.

Altitude of water table in pre-monsoon ranges from 190 meter in north-west to 162 meter in the south-east above the mean sea level.

Regional groundwater flow is from NW to SE with some local variations at places caused due to some local factors. Hydraulic gradient is generally steeper close to the Mat feeder canal than the other part of the study area, indicating that the sediments are finer and have low permeability horizons. The hydraulic gradient varies from 0.50 m/km to 2.5 m/km. Further, the contour behaviour shows that Yamuna and Karwan rivers are effluent in nature except close to the Chinpari and Nurpur where the Yamuna river shows an influent nature. This reversal of hydraulic gradient is the resultant effect of the excessive withdrawl of the groundwater in the area. The post monsoon contours show almost similar behaviour as in pre-monsoon period due to scanty rainfall in the study area.

Rainfall is the main source of groundwater recharge. Besides, canal seepage and irrigation return flow form the secondary sources of groundwater recharge. The hydrographs of the key observation wells show that the water level variation is cyclic and sinuosoidal as a function of time and space. It shows that the response of water level to rainfall and drought is reasonably quick in space and time. The ascent of level is also greatly affected by the intensity, duration and distribution of the rainfall in the area. Hydraulic conductivity values of the aquifer materials and of Yamuna and Karwan rivers sands claculated through the mechanical analysis, ranges from 25.40 to 132.71 m/day and 43.87 to 84.93 m/day respectively. Isopermeability map (prepared after Logan's method) indicates four zones i.e. <25, 25-30, 30-35 and >35 m/day.

The pumping tests and data anlysis results reveal that the transmissivity and storativity values determined as 503 m^2/day and $1.34x10^{-4}$, respectively. The hydraulic conductivity value is determined as 18.64 m/day. The result of the pumping test further shows that the shallow aquifers are unconfined in nature while the deeper aquifers are under confined conditions.

The quality of groundwater is equally important as its quantity. Water samples collected from various surface sources and groundwater structures were analysed for various constituents affecting the quality and its suitability for drinking and irrigational purposes. Chemically, the groundwater in the area belongs to Bicarbonate facies of anion group and Na-K type of cation facies.

The groundwater in the study area is potable, hard, alkaline in reaction and moderately mineralised and alkaline-bicarbonate type. The occurrence of slightly higher fluoride (1.89 ppm) content in shallow aquifer water in the some villages of Nojhil block may pose health hazards to the users.

The concentration of heavy toxic metal (Fe, Cr, Pb and Cd) in the shallow aquifer was found more than their limits but their concentration in deeper aquifer samples were found well within the permissible limit. By and large the groundwater of the study area is suitable for drinking as well as irrigational purposes.

In surface water samples the concentration of major ions is far less than the groundwater in the sub-basin. However, the concentration of trace elements in water samples of the Yamuna and Karwan rivers are much higher than their standard limits. The heavy metal concentration is attributed to the Delhi metropolis effluents. If the present pollution continues unchecked, potable water for domestic and other purposes may be difficult to manage.

Certain environmental problems like water logging, soil salinization and bad land tracts have been delineated and remedial measures suggested.

Evaluation of groundwater resource of Yamuna-Karwan sub-basin was also attempted. It reveals that net groundwater recharge in the sub-basin is 29566.0 ham. and net draft is 15023.96 ham, leaving a balance of 14542.04 ham. as the utilisable groundwater resource which can be utilised through the construction of about one thousand shallow tubewells (having discharge of 15-25 m^3/hour at an economic draw-down) and 100 deep tubewells (with 70-120 m^3/hour pumping rate at a drawdown of 4 to 6 meters) in phases over a period of five years. Constant monitoring of the effect of groundwater development all over the basin be done on regular basis to observe adverse effect if any.

As per NABARD's norms the stage of groundwater development in the Yamuna-Karwan sub-basin was estimated as 50.81% and consequently it falls under the white or safe category.

The present quantitative and qualitative evaluation of groundwater resource potential of Yamuna-Karwan sub-basin may be useful to the planners and administrators for the integrated development of the area. Regular monitoring of the water level vis-a-vis the pace of groundwater development in the area be carried out. The declining water levels at places consequent to the excessive withdrawl, it is suggested that further exploitation of groundwater should be permitted cautiously. Moreover, some schemes of artificial recharge through canal network to contain the declining trend of water level be implemented.

The areas where water table is constantly rising due to seepage, canal beds be lined. Conjuctive use of surface and groundwater will greatly help achieve the utilisation of water resources.

In future, in the opinion of the author, when there will be large scarcity of the water, the use of drip and sprinkler irrigation methods (particularly for uneven topography in the area), recycling of wastewater and desalination of deeper aquifer (as aquifer below 100 mts are all saline down to the bed rock) brakish/saline water may play a vital role in increasing agricultural production in the area.

Finally, if such study is extended to the other parts of the Ganga basin in a stipulated time, may help emerge a harmonious hydrogeological picture of the entire Ganga basin.

REFERENCES

REFERENCES

Agarwala, V.K. and Raj, K.P.S. 1978. Metal contents in the drinking water of cambay Basin, Air and Soil Pollution, pp. 9-429.

Agarwala, R.R. and Malhotra, C.L. 1957. Soil survey and soil work in U.P., vol. I.

Agarwal, M.C. and Mallik, R.K. 1982. Consequences of Irrigated Agriculture in Arid and Semi-Arid Areas of Groundwater Regime, Intern. Symp. IAH, Prague Czechoslovakia, "Impact of Agricultural Activities on Groundwater".

Agricultural, Refinance and Development Corporation, 1970. Report of Groundwater over-exploitation committee, p. 93.

Ahmad, F. 1957. A preliminary note on the groundwater in the Ghar area of Saharanpur district, U.P. Proceedings Indian Science Congress.

American Public Health Association, 1975. Standard methods for the examination of water and waste water, 14 edition, APHA, Washington D.C.

Anon, 1975. "Manual of Standards of Quality of Drinking Water Supplies" 2nd ed. Special Report Series No. 44, Indian Council of Medical Research, New Delhi.

Anon, 1977. Outbreak of Paralysis in villages of Unnao district, U.P. - A Preliminary Epidemiological Study, ITRC Memoir, no. 1.

Asgar, A.G., Puri, A.N. and Taylor, A.M., 1936. Soil deterioration in irrigated areas of Punjab, Part-I-II, Irrigation Research Inst. Memoir, Amritsar.

Auden, B., 1933. Vindhyan Sedimentation in the Son Valley, Mirzapur district, Mem. Geol. Surv. Ind. v. 62.

Ayers, R.S. and Westcot, D.W., 1976. Water quality for agriculture, Irrig. and Drain. Paper No. 29, F.A.O. Rome.

Ayers, R.S. and Branson, R.L., 1975. Guidelines for interpretation of water quality for agriculture, University of California, Extension Mimeograph, pp. 13.

Back, W., 1966. Hydrochemical facies and groundwater flow patterns in northern part of Atlantic Coastal Plain, U.S. Geol. Surv. Prof. Paper 498-A, pp.42.

Back, W., 1961. Techniques for mapping of hydrochemical facies. U.S. Geol. Surv. Prof. Paper 424-D. pp. 380-382.

Back, W. and Hanshaw, B.B. 1965. Chemical Geophydrogeology. Adv. Hydrosci., 2, pp. 49-109.

Bally, A.W., 1981. Thoughts on the tectonics of folded belts in thurst and Nappe-Tectonics (Ed. by K.R. McClay and N.J. Price), pp. 13-32 Spect. Pub. Geol. Soc. London 9.14.9, 14.9.2.

Basu, A.K., 1983. Groundwater Pollution and its control. Proc. Seminar on GW for Rural and Urban Water Supply INC, International Association of Hydrogeologists, Calcutta.

Baweja, B.K. and Karanth, K.R., 1980. Groundwater recharge estimation in India Tech. Series H. Bull. 2. Central Groundwater Board.

Baweja, B.K. and Karanth, K.R., 1980. Groundwater Pollution Studies in India Tech. Series H. Bull. 5. Central Groundwater Board.

Bear, J. and Verruyt, A., 1987. Modeling Groundwater Flow and Pollution. D. Reidel Publishing Company, Dordrecht, Holland, 414 P.

Beaumount, C., 1981. Foreland basins. Geophys. J.R. Astro. Soc., v. 65, 291-329.

Bedinger, M.S., 1961. Relation between median grain size and permeability in the Arkansas River Valley, Arkansas, U.S. Geol. Surv. Professional Paper 292, P.

Berg, J.W. and Burbank, F. 1972. Geochemical environment in relation to health and disease. Ann. N.Y. Acad. Sci. 199, PP. 249-264.

Biswas, A.B. and Saha, A.K., 1983. Groundwater resources of India with special references to their salinity and pollution hazards, In Varshney, C.K. (Edt) Water Pollution and Management Review 1982, pp. 113-127.

Bhaduri, D. and Behra, U.K., 1984. Quaternary Geology and Geomorphology of a part of Yamuna Basin in Aligarh and Mathura districts, U.P. G.S.I. Report.

Bhattacharya, A.P., Jindal, S.R. and Srivastava, B.P. 1954. Penetration of rainwater to groundwater table in Western U.P., India, U.P. I.R.I. Tech. Memoir No. 25.

Boulton, N.S., 1963. Analysis of data from non equilibrium allowing for delayed yield from storage. Proc. Inst. Civil Engg. V-26, pp. 469-482.

C.G.W.B., 1982. Evaluation of Aquifer Parameters, a manual, Central Groundwater Board, Ministry of Irrigation, Govt. of India. pp. 183.

Chakarvarti, C.R., 1986. Distribution of fluoride species in Groundwater of Cuttack District and its Defluoridation Technique. Proc. Seminar on GW for Rural & Urban Water Supply INC, IAH, Calcutta.

Chandra, S. 1979. Estimation and measurement of recharge to groundwater from Rainfall, Irrigation and Influent Seepage, Proc. of Inter. Seminar on Development and Management of Groundwater Resources, Univ. of Roorkee, India, pp. III 9 - III 17.

Cherry, A. John., and Freeze, R.A., 1979. Groundwater, Prentice-Hall, Inc, Englewood Cleffs, N.J. 07632, pp. 604.

Chisholm, J.J. 1971. Lead Poisoning Scient. Am., V. 224, pp. 15-23.

Cohen, J.M. et al., 1960. Taste threshold concentrations of metals in drinking water, Jour. Amer. Water Works Assn. v. 52, pp. 660.

Cohen, Phillip, 1963. Specific yield and particle size relations of quaternary alluvium, Humbolt River Valley, Nevada, U.S. Geol. Surv. Water Supply paper, 1669-M.

Collins, W.D., 1923. Graphic representation of water analyses, Ind. and Eng. Chem., vol. 15, p. 394.

Colucci, A.V., Winge, D. and Krasco, J. 1975. Cadmium accumulation in the rat liver. Arch. Envi. Health. 30 pp. 153-157.

Commission of the European Communities, 1978. Criteria (dose/effects relationships) for cadmium, Oxford, pergamon Press.

Copper, H.H., Jr., and C.E. Jacob, 1946. A generalised graphical method for evaluating formation constants and summarising well-field history. Trans. amer. Geophysical Union, vol. 27, pp. 526-534.

Craun, G.F. and Mc Cabe, L.J., 1975. Problems associated with metals in drinking water, J. Am. Wat. Wks. Assoc., 67. pp. 593-599.

Crawford, A.R., and Compston, W., 1970. The age of the Vindhyan System of Peninsular, 125(3), pp. 351-371.

Darcy, H. 1856. Lesfentaines Publiquesdela ville de Dijon, V. datmont Paris, 657 p.

Das, D.K., 1977. Report on a study visit for Training in Atomic Absorption Spectroscopy and other Geochemical Techniques - Related to Betwa Valley Groundwater Project, India.

Das, D.K. and Kidwai, A.L., 1983. Quality of Irrigation water with respect to trace elements in Upper Catchment of Betwa river basin, M.P. and U.P. Proc. Sem. on Ass. Devel. Manage. of Groundwater Res., vol. I, pp. 345-355.

Datta, A.N., Mishra, D.C., Ghosh, D. and Banerjee, B., 1990. Geomorphotectonics of the Basement in a part of Upper Son Valley of the Vindhyan Basin, Jour. Geol. Soc. Ind. v. 35, pp. 445-458.

Datta, A.N., Bala Krishnan, T.S., Ghosh, A.P., Mohan, V.C. and Nath R., 1964. Seismic Surveys in the Punjab Plains, Proc. 22nd Int. Geol. Congr., New Delhi, vol. 2, pp. 248-259.

Davis, S.N. and Dewiest, 1966. Hydrogeology, John Willey and Sons, p. 463.

Dickinson, W.R., 1974. Tectonics and Sedimentation. Spec. Pub. Soc. Econ. Paleont. Mine, v. 22, pp. 1-27.

Drinking Water and Health, 1980, vol. 3, National Research Council, Washington, D.C.

Drinking Water and Health, 1977. Part I, National Research Council, Washington, D.C.

Dutt, D.K., 1969. Hydrogeology of the Aligarh district, Uttar Pradesh, Indian Minerals, vol. 23(2), pp.1-14.

Eaton, F.M., 1950. Significance of carbonate in irrigation water, Soil Sci., vol. 69, No. 2, pp. 123-133.

Environmental Protection Agency, 1973. Water quality Criteria, EPA Publ. E.P.A., R. 3-73-033, p. 594.

Epstein, E., 1965. Mineral Metabolism in Plant Bio-chemistry, Bonner, J. Varner, J.E. Eds. Acad. Press, New York, pp. 438-466.

Fairbanks, V.F., Fahey, J.L. and Bentler, E. 1971. Clinical Disorders of Iron Metabolism, 2nd ed. Grune and Stration. New York, pp. 486.

Faruqi, N.H., 1988. Incidence of Fluorides in Groundwater Resources in the Southern Punjab and its Environmental Management, Proc. of ISEG Symp. on Environ. Manage; Journ. of Engg. Geol. Vol. XVII, No. 1 & 2, Calcutta, pp. 57-64.

Favero, M.S. and Drake, C.H., 1964. Public Health Reports, 79, p. 251.

Fedral Water Pollution Control Authority, U.S.A., 1968. Report of the Committee on Water Quality Criteria, Washington D.C., p. 234.

Fergusson, J.E., 1990. The heavy elements: Chemistry, environmental impact and health effects, New York, Pergamon Press.

Fetter, C.W., 1988. Applied Hydrogeology (Second Edition), Merrill Publishing Company, Ohio, pp. 529.

Fetter, C.W.J.R. 1985. Final Hydrogeologic Report, Seymour Recycling Corporation Hazardous Waste Site, Seymour, Indiana, Submitted to United States Environmental Protection Agency, 1985, pp. 171.

Fleisher, M., Sarofim, A.F., Fassett, D.W., Hamnond, P., Shacklette, H.T., Nisbet, I.C.T. and Epstein, S. 1974. Environmental impact of cadmium, A review by the Panelon the Hazardous Trace Substances, Environ. Health Perspect Vol. 7 pp. 253-323.

Fletcher, G.D., 1986. Groundwater and Wells, Sec. Edit. Published by Jhonson Div., St. Pul Minnesota, pp. 1089.

Fluori, R.C., 1969. Geological Framework on Ganga Basin, Selected Lectures on Petroleum Expln. vol. 1, Inst. Petr. Expln. ONGC, pp. 170-186.

Food and Drug Administration, 1975. Toxicity of essential minerals information pertinent of establishing appropriate levels of single mineral dietary supplements, Division of Nutrition Bureau of Foods, Food and Drug Administration Washington D.C., p. 231.

Forstner, U, and Wittman, G.T.w., 1983. Metal pollution in the aquatic environment. New York, Springer-Verlag, pp. 486.

Freeze, R.A. and Cherry, J.A., 1979. Groundwater Englewood Cliffs, N.J., Prentice Hall, pp. 604.

Friberg, L., Piscator, M., Nordberg, G.F. and Kjellstom, TT., 1974. Cadmium in the Environment, 2nd ed. CRC Press, Cleveland, pp. 248.

Frieden, E., 1972. The chemical elements of life, Scientific American, vol. 227, pp. 252-260.

Furman, N.H., 1962. Standard methods of chemical analysis, 6th ed. vol. 1, New York: Van Nostrand, pp.229-1278.

Galgan, D.J. and Vermilian, J.R., 1957. Determining Optimum Fluoride Concentrations. Publ. Hlth. rep. Wash. 72, pp. 491-503.

Ganser, A., 1964. Geology of Himalayas, Interscience Publishers. John Wiley and Sons, pp. 287.

Geddes, A., 1960. The alluvial morphology of the Indogangetic plains, Trans. Inst. br. Geogr., pp.253-276.

Ghai, O.P., 1990. Essential Pediatrics, Second revised and enlarged edition, Interprint, New Delhi, pp. 427.

Ghosh, D.K., and Singh, I.B., 1988. Structural and geomorphic evolution of the north-west part of the Indo-gangetic plain. Proc. Nation. Sem. Recent Quaternary Studies in India, Deptt. of Geology, M.S. University of Baroda, pp. 164-175.

Goel, D.K., 1983. Pollution of Groundwater by Potassium in Uttar Pradesh. Proc. C.G.W.B. Seminar on Assessment Dev. & Management of GW, Res. vol. II.

Goyer, R.A. and Rhyne, 1974. Pathological effect of lead. Rev. Exp. Pathol., Vol. 12, pp. 17.

Groundwater Estimation Committee, 1984. Groundwater Estimation Methodology. A report, Ministry of Irrigation, Govt. of India, New Delhi.

Guidelines for Canadian drinking water quality, 1978. Quebec, Ministry of Supply and Services, 1979 (Supporting documentation).

Gupta, D.C. 1989. Irrigational suitability of surface waters for agricultural development of the area around Mandu, District Dhar, M.P., India, Jour. Appl. Hydr. Vol. II, No. 2, pp. 63-71.

Gupta, M.C. and Gaumat, M.M., 1983, Distribution of fluoride in shallow aquifers, Uttar Pradesh. Proc. of Seminar on Assessment, Development and Management of GW Resources, Vol. I, p. 283.

Handa, B.K., 1984. Methods of collection and preservation of water samples Tech. Man., CGWB. Ministry of Water Resource Govt. of India, pp. 40.

Handa, B.K., 1986. Pollution of Natural Waters in Uttar Pradesh, Findings of Central Chemical Laboratory, C.G.W.B. Bhu-Jal News Vol. 2 No. 1, Jan-March, 1986.

Handa, B.K., 1987. Groundwater Pollution Problems on the Indian Sub-continent and their Management. Proc. Sem. on GW for Rural & Urban Water Supply INC, IAH, Calcutta, pp. 87.

Handa, B.K., 1988. Fluoride occurance in natural waters in India and its significance. Bhu-jal News Vol. 3, No.2 April-June, 1988.

Handa, B.K., 1983. The effect of fertilizer use on ground-water quality in the pheratic zone with special reference to U.P. Proc. Seminar on Assessment, Development & Management of Groundwater Resources, CGWB, New Delhi, vol. II, pp. 415-425.

Handa, B.K., 1977. Modern methods of water analysis. Tech. Manual No. 3, CGWB, Min. of Agr. & Irr. pp. 1-404.

Hantush, M.S., 1956. Analysis of data from pumping tests in leaky aquifers Trans. Amer. Geophysical Union, v.37, pp. 702-714.

Hari Narain and Kalia, K.L. 1982. Inference about the Vindhyan basin from Geophysical data in; Valdiya, K.S. Bhatia, S.B. and Gaur, V.K. (eds. Geology of Vindhyachal, Hindustan Pub. corpn. India), Delhi, India.

Harr, M.E., 1962: Groundwater and Seepage, New York, McGraw Hill Book Co., p. 315.

Hassan, N., Johri, P.K. and Hassan, F., 1982. Intensive geophysical investigation, Block Jagat, district Badaun, U.P.

Hazen, A., 1983. Some physical properties of sands and gravels, Mass State Board of Health, 24th Annual Report.

Hem, J.D.,1959. Study and interpretation of the chemical characteristics of natural water. U.S. Geol. Survey water Supply Paper, 1473.

Herman and Bouwer, H., 1978. Groundwater Hydrology, McGraw Hill (McGraw Hill Series in water resource and environmental engineering, pp. 408.

Hill, R.A., 1940. Geochemical patterns in Coachella Valley. Trans. ame. Geophys. Union, 21, Part I, washington, D.C., pp. 46-53.

Hubbert, M.K., 1940. Theory of groundwater motion. Jour. Geol. vol. 48, pp. 758-944.

Indian Council of Medical Research, 1975. Manual of standards of quality for drinking water supplies, I.C.M.R., New Delhi 2nd ed.

Indian Standard Institution, 1983. Drinking water standards, Table 1, Substances and characteristics affecting the acceptibility of water for domestic use.

Itokawa, Y., Abe, t., Tabei, R. and Tanaka, S., 1974. Renal and skeletal lesions in Experimental cadnium poisoning Arch Envrion., Health, 28 pp. 149-154.

Jackson, M.L., 1958. Soil Chemical Analysis, Constable & Co. Ltd., pp. 452.

Jacob, C.E. and Cooper, H.H., Jr. 1946. A generalized graphic method for evaluating formation constants and summarizing well field history transactions. Amer. Geophy. Union, vol. 27, pp. 526-34.

Johnson, A.E., 1963. Application of Laboratory permeability data, USGS, open file report.

Jolly, S.S., Oberai, D.K. and Sharma, R. 1974. Fluoride balance studies in cases of fluorisis endemicity. Proc. of Symp. on Fluorisis, Hyderabad.

Jones, G.P. and Rushton, K.R., 1981. Pumping test analyses, case-studies in Groundwater Resource Evaluation, Ed. (J.W. Lloyd). Oxford Science Publications, pp. 65-86.

Karanth, K.R., 1987. Groundwater assessment, development and management, McGraw Hill Publishing Co. Ltd., New Delhi, pp. 720.

Karanth, K.R., 1986. Waterlogging-causes, prevention and control. Proc. Sem. on Conjuctive use of surface and groundwater resources, CGWB, New Delhi, pp.4A1-28.

Karunakaran, C. and Rao, A.R., 1976. Status of exploration for hydrocarbon in the Himalayan region - contribution to stratigraphy and structure. Himalayan geology seminar. Sec. III, New Delhi, Misc. Pub. Geol. Surv. India 1979, 41(5), pp. 1-66.

Kelley, W.P., Brown, S.M. and Liebig, G.F. Jr., 1940. Chemical effects of saline irrigation waters on soils, Soil Sci., vol. 49, pp. 95-107.

Khan, A.U. and Nigam, A.C., 1986. Report on quaternary geology and geomorphology of a part of Yamuna basin, Aligarh and Mathura distt. U.P., G.S.I. Ind.

Khurshid, S. and Israili, S.H., 1988. An assessment of pollution load and the quality of water in western part of Yamuna river basin. Journ. of Engg. Geology, ISEG, Calcutta, Vol. XVII Nos. 1&2, pp. 71-80.

Khurshid, S., Arif, K.A. and Hasan, N., 1992, Dispersion of Heavy Metals in Surface and Groundwater Bodies in the Hindon River Basin, India, Proc. of VIII Congress of the Asian and Pacific Regional Div. of International Association for Hydraulic Research, vol. I, pp. E-159-E-169.

Krishnan, M.S., 1968. Geology of India and Burma, Sixth edition C.B.S. Publisher, India, pp. 536.

Krumbein, W.C., and Monk, C.V., 1942. Permeability as a function of the size parameters of unconsolidated sand, Trans Amer. Inst. Min. Met. Engr. Vol. 151, pp. 153-163.

Kruseman, G.P., and de Ridder, N.A., 1970. Analysis and evaluation of pumping test data. Bull 11, Intl. for Land Reclamation and Improvement, Wegeningen Netherland.

Leopold, L.B., Wolman, M.G. and Miller, J.P., 1964. Fluvial Process in Geomorphology, W.H. Freeman and Co., San Francisco and London, pp. 522.

Lochhart, E.E., Tucker, C.L. and Merritt, M.C., 1955. The effect of water impurities on the flavour of brewed coffee, Food Res 20, pp. 598-605.

Logan, 1964. Estimating transmissivity from routine production tests of water wells. Groundwater vol. 2, No.1, pp. 35-37.

Marsily, G. de., 1986. Quantitative Hydrogeology, Academic Press, California, pp. 435.

Masch, F.D., and Denny, K.J., 1966. Grain size distribution and its effect on the permeability of unconsolidated sands, Water Resource Research, v. 2, pp. 665-677.

Mathess, G., 1982. The properties of groundwater. John Wiley & Sons, New York, pp. 406.

Mathess, G., 1972. Hydrogeologic Criteria for the self purification of polluted groundwater. Proc. 11th Int. Geol. Cong., Montreal, pp. 296-302.

Miall, A.d. 1981. Alluvial sedimentary basins: tectonic setting and basin architecture. In Sedimentation and Tectonics in Alluvial Basins (Ed. by A.D. Miall), Spec. Pap. Geol. Ass. Can., 23, 14, 2.5, 14.3, 14.9.2, pp. 1-33.

Morgan, C.O. and Winner, M.D. 1962. Hydrochemical facies in the 400 foot and 600 foot sands of Baton Rouge Area, Lusiana U.S. Geol. Surv. Prof. Paper 450-B, pp. B 120-121.

Mukerji, A.B., 1963. Alluvial Morphology of the Upper Ganga-Yamuna doab, The Deccan Geographr, Hyderabad vol. 2(1), pp. 31-39.

National Academy of Sciences Safe Drinking Water Committee, 1977. Drinking Water and Health, Washington, D.C. 20418, USA.

Neri, L.C., Hewitt, D., Schreiber, G.B., Anderson, I.W., Mandel, J.G. and Zotrojewsky, A., 1975. Health aspects of hard and soft waters. J. Am. Wat. Wks. Assoc. No. 67, pp. 403-409.

Nevill, H.R., 1909. District Gazetteers of the United Provinces of Agra and Oudh. Vol. VI. ALIGARH, a Gazetteer.

Oldham, R.D., 1917. The structure of the Himalayas and the Gangetic Plains, Mem. Geol. Surv. Ind., v. 2(2), pp.153.

Olwin, J.H., 1977. Metals in the life of man, Jour. Anal Toxic, No. 1, pp. 245-251.

Paliwal, K.V., 1972. Irrigation with saline water. I.A.R.I. Monograph No. 2 (New Series), New Delhi, pp. 198.

Parkar, C.R., 1972. Water analysis by Atomic Absorption Spectroscopy, Varian Techtron Pvt. Ltd., Australia.

Pascoe, E.H., 1964, A manual of Geology of India and Burma, Govt. of India Press, Calcutta, pp. 21.

Pathak, B.D., 1978. Hydrogeology and groundwater Potential of U.P., Central Groundwater Board Publication.

Pathak, B.d., 1982. Groundwater resources and development potential in India, CGWB, Govt. of India, pp. 112.

Pathak, B.D., 1985. Groundwater in India and scope for future development, current trends in Geology VII-VIII, pp. 573-577.

Pathak, B.D., 1988. Groundwater its development potential and problems in Indo-Gangetic plain, Bhu-Jal News, Qut. Jour. of CGWB, vol. 3, pp. 29-33.

Pathak, B.D., Sinha, B.P.C., Kidwai, A.L., Raju, T.S., Chaturvedi, P.C. and Singh, B.K., 1985. Tectonics, sub-surface geology and groundwater occurrence in Ganga-Basin and proposals for deep drilling with special reference to Uttar Pradesh, Central Ground-water Board, pp. 49.

Piper, A.M., 1944. A graphic procedure in the geochemical interpretation of water analysis. Trans. Amer. Geophysical Union, vol. 25, pp. 914-928.

Preuss, F.A. and Todd, D.K., 1963. Specific yield of unconsolidated alluvium, W.R.C.C., No. 76, Univ. of California, pp. 12-18.

Prickett, T.A., 1965. Type curve solution to aquifer tests under water table conditions groundwater, vol. 3 No.3, pp. 5-14.

Raghava, Rao, K.V., Raju, T.S. and Ramesam, V., 1969. An estimation of groundwater potential of India-Approximation Soil and Water Management Symposium, Hissar, ICAR, pp.8.

Raghunath, H.M., 1987. Groundwater second edition, Wiley Eastern Limited, pp. 563.

Rainwater, F.H. and Thatcher, L.L. 1960. Methods for collection and analysis of water samples, United States Govt. Printing Office, Washington, D.C.

Raiverman, V., Kunte, S.V. and Mukherjee, 1983. Basin geometry, Cenozoic sedimentation and Hydrocarbon prospects in North-Western Himalaya and Indo-Gangetic plain, Petroliferous basins of India, Peteroleum Asia Journal India, pp. 67-91.

Ramamoorthy, B., 1964. Some aspects of the management of soil water plant climatic complex in the zone, Proc. General Symp. Problems of Arid zones, CAZRI Jodhpur, pp. 276-285.

Ramesam, V., 1987. Groundwater research an introductory Overview Jour. Geol. Soc. of India, Vol. 29, No. 1, pp. 1-5.

Ramesam, V., 1989. Research and development in water resources. Jour. of Geol. Soc. of India, vol. 34, No. 1, pp. 345-350.

Rao, A.A. 1986. Groundwater planning and management, Bhu-Jal News, Qut. Jour. of CGWB. vol. 1 No. 4, pp. 14-16.

Ramachandra Rao, M.B., 1973. The sub-surface geology of the Indo-gangetic plains. Jour. Geol. Soc. Ind. Vol. 12, No. 3, pp. 217-242.

Rastogi, R. and Gaumat, M.M., 1990. Pollution of groundwater in Mathura district, Uttar Pradesh, Bhu-Jal News, Qut. Jour. of CGWB vol. 5, No. 2, pp. 49-51.

Reading, H.G., 1986. Sedimentary Environments and Facies, Second edition, Black Well Scientific Publications Oxford London.

Riddick, T.M. et al. 1958. Iron and Manganese in water supplies. Jour. Amer. Water Works Assoc. vol. 50, pp. 680.

Saligram, V.K., 1961. Standards of suitability of underground irrigation water with special reference to tubewells in North Gujrat, Paper presented at Seminar in Irrig. Draig and Water logging, Bombay.

Sally, H.L., 1968. Irrigation planning for Intensive Cultivation, Asia Publishing House, Bombay, pp.205.

Sastri, V.V. Bhandari, L.L., Raju, A.T.R. and Datta, A.K., 1971. Tectonic framework and sub-surface stratigraphy of the Ganga-Basin, Jour. Geol. Soc., Ind., vol. 12, No. 3, pp. 222-233.

Satish Chandra, 1983. Hydrogeological investigations in groundwater Resource Evaluation. Proc. Seminar on Assessment, Development and Management of Groundwater Resources, Central Groundwater Board, New Delhi.

Schroeder, H.A. and Kramer, L.A., 1974. Cardiovascular moratlity, Municipal Water and Corrosion Archs. Environ. Health, vol. 28, pp. 303-311.

Seaber, P.R., 1962. Cation hydrochemical facies of ground-water in the English town formation. New Jersy, U.S. Geol. Surv. Prof. paper 450-B, pp. 124-126.

Sharma, C.B. and Ghosh, N.C., 1987. Pollution of the river Ganga by municipal waste: a case study from Patna, Jour. Geol. Soc. of Ind. Vol. 30, pp. 369-385.

Sharma, H.D., and Chawla, A.S., 1977. Manual on Groundwater and Tubewells, Tech. Report No. 18, C.B.I.P., New Delhi, pp. 200.

Singhal, B.B.S., Mathur, R.P., singhal, D.C., Mathur, B., Minocha, V.K., Seth, A.K. and Sinha, S.K., 1987. Effects of industrial effluents on the water quality of river Hindon, district Saharanpur, U.P. Jour. Geol. Soc. Ind. vol. 30, pp. 356-348.

Singh, I.B., 1987. Sedimentological history of quaternary deposits in gangetic plain. Indian Jour. Earth Sci. Vol. 14, pp. 272-282.

Singh, I.B., 1989. Sedimentation Pattern in Gangetic plain, India: Active Foreland basin 28th I.G.C. Washington D.C. Abstract vol. 3, pp. 122.

Singh, I.B., Bajpai, V.N., Kumar, A. and Singh, M., 1990. Changes in Channel Characteristics of Ganga River during late pleistocene - Holocene, Jour. Geol. Soc. India vol. 36(1), pp. 67-73.

Srivastava, B.N., Rana, M.S. and Verma, K., 1983. Geology and Hydrocarbon prospects of the Vindhyan Basin. Petroliferous Basin of India, pp. 179-189.

Statistical Book, 1992-93. Aligarh and Mathura districts, Economics & Statistics Division, State Planning & Institute, Govt. of Uttar Pradesh, Lucknow.

Stiff, H.A. Jr., 1951. The interpretation of chemical water analysis by means of pattern. Jour. Petr. Technology vol. 3(10), pp. 15-17.

Suess, E., 1904-1924. The face of the earth. vol. 5. Clarendon Press, Oxford.

Sunderman, F.W. 1977. A review of the metabolism and Toxicology of Nickel, Ann. Clin. Lab. Sci. 7(5) pp.377-98.

Synder, R.B., Wuebbles, D.J., Pearson, J.E. and Ewing, B.B., 1971. A study of environmental study. Estate of Illions II EQ Document No. 717.

Taylor, G.C., 1959. Groundwater Provinces of India, Economic Geology, vol. 54, pp. 683-697.

Thies, C.V., 1935. The relation between the lowering of the piezometric surface and rate and duration of discharge of a well using groundwater storage. Transaction, american Geophysical Union vol. 16, pp. 519-524.

Thiem, G., 1906. Hydrologicsche Methoden. Gebhardt, Leipzig pp. 56.

Todd, D.K., 1980. Groundwater hydrology, 2nd edition, John Willey and Sons, pp. 535.

Towill, L.E. et al., 1978. Reviews of the environmental effect of pollutants, III, Chromium, U.S. Department of Commerce, National Technical Information Service, pp. 282-796.

Train, R.E., 1979. Quality criteria for water, London Castle House, pp. 256.

Trivedi, R.K. and Goel, P.K., 1984. Chemical and Biological Methods for water pollution studies. Envt. Pub. Karad, India, pp. 215.

Uma, K.O., Egboka, B.C.E. and Onuoha, K.M., 1989. New statistical grain size-method for evaluating the hydraulic conductivity of sandy aquifers. Jour. of Hydrology 108, pp. 343-366.

Underwood, E.J., 1977. Trace elements in human and animal nutrition. Academic Press, New York.

Upadhyay, D.S., Mukerjee, K., and Guha, K.B., 1989. Droughts in India, Abstract vol. National Workshop on arid zone research RSACREG, A.M.U., Aligarh, India.

USDI, 1985. Groundwater Manual, A water resources technical publication, U.S. Deptt. of the Interior, Scientific Publishers, India, pp. 480.

USEPA, 1983. National Revised Primary Drinking Water Regulations, Federal Register Octob. 5, 48 (194), Part II.

USPHS, 1962. United States Public Health Service, Drinking Water Standards Publications No. 956, U.S. Govt. Printing Office, Washington, D.C.

U.S. Salinity Laboratory Staff, 1954. Diagnosis and improvement of saline and alkaline soils, U.S.D.A. Handbook No. 60, pp. 160.

Valdiya, K.S., 1976. Himalayan Traverse faults and folds and their parallelism with sub-surface structures of North Indian Plates. J. Tectonophysics V. 32, pp.353-386.

Valdiya, K.S., Bhatia, S.B. and Gaur, V.K., 1982. Geology of Vindyachal, Hindustan Pub. Corp. India.

Valdiya, K.S., 1984. Aspects of Tectonics focus on South Central Asia. Tata McGraw Hill Pub. Co. Ltd., pp.319.

Verma, R.C., 1989. A study of groundwater quality in parts of Aligarh-Mathura districts - A Report, G.W.D.U.P.

Wadia, d.N., 1957. Geology of India 3rd edition, Macmillan, London, pp. 356.

Walton, W.C., 1962. Selected analytical methods for well and aquifer evaluation, Bull. 49, Illinois State water Survey, Urbana, pp. 81.

Walton, W.C., 1970. Groundwater resource evluation, McGraw Hill Series in Water Resources and Environmental Engineering, McGraw Hill Book Co., New York, pp.664.

Webb, M., 1975. Cadmium, Br Med. Bull vol. 31, pp. 246-250.

Wilcox, L.V., 1955. Classification and use of Irrigation water U.S. Deptt. of Agri. Circ. 969, Washington, D.C., pp. 19.

World Health Organisation, 1984. Guidelines for Drinking Water Quality, vol. 1&2, Recommendations, W.H.O. Geneva.

World Health Organisation, 1973. Technical Report Series: Trace elements in Human Nutrition, Report of a WHO Expert Committee, No. 532.

APPENDICES

APPENDIX - I(A)

RAINFALL DATA ANALYSIS OF KHAIR RAIN GAUGE STATION

The mean of 93 yrs of rainfall ($\bar{X}$) = 721.81 mm

The standard deviation = 232.57

The Coefficient of variation = 32.220

S.No.	YEAR	ANNUAL RAINFALL X	DEPARTURE	CUMULATIVE DEPARTURE	$(X-\bar{X})$	$(X-\bar{X})^2$
1	1901	825	0.14	0.14	103.19	10648.17
2	1902	411	-0.43	-0.29	-310.81	96602.85
3	1903	776	0.07	-0.22	54.19	2936.55
4	1904	404	-0.44	-0.66	-317.81	101003.20
5	1905	465	-0.35	-1.01	-256.81	65951.37
6	1906	383	-0.47	-1.48	-338.81	114792.22
7	1907	499	-0.31	-1.79	-222.81	49644.29
8	1908	794	0.10	-1.69	72.19	5211.39
9	1909	443	-0.38	-2.07	-278.81	77735.01
10	1910	935	0.24	-1.78	213.19	45449.97
11	1911	557	-0.22	-2.00	-164.81	27162.33
12	1912	315	-0.56	-2.56	-406.81	165494.38
13	1913	352	-0.23	-2.79	-169.81	28835.43
14	1914	694	-0.03	-2.82	- 27.81	773.39
15	1915	950	0.31	-2.51	228.19	52070.67
16	1916	921	0.27	-2.24	199.19	39676.65
17	1917	441	-0.39	-2.63	-280.81	78854.25
18	1918	361	-0.49	-3.12	-360.81	130183.86
19	1919	804	0.11	-3.01	82.19	6755.19
20	1920	349	-0.51	-3.52	-372.81	138987.30
21	1921	895	0.24	-3.28	173.19	29994.77
22	1922	645	-0.10	-3.38	- 76.81	5894.77
23	1923	790	0.10	-3.28	68.19	4649.87
24	1924	860	0.17	-3.11	138.19	19096.47
25	1925	887	0.22	-2.89	165.79	27287.73
26	1926	549	-0.23	-3.12	-172.81	29863.29
27	1927	880	0.21	-2.91	158.20	25027.24
28	1928	797	0.10	-2.81	75.19	5653.53
29	1929	452	-0.37	-3.18	-269.81	72797.43
30	1930	793	0.10	-3.08	71.19	5068.01
31	1931	721	-0.00	-3.08	- 0.81	0.65
32	1932	886	0.22	-2.86	64.19	26958.35
33	1933	517	-0.28	-3.14	-204.81	41947.13
34	1934	628	-0.13	-3.27	- 93.81	8800.31
35	1935	700	0.06	-3.21	48.19	2322.27
36	1936	622	-0.13	-3.34	- 99.81	9962.03
37	1937	992	0.37	-2.97	270.19	73002.63
38	1938	522	-0.27	-3.24	-199.81	39924.03
39	1939	782	0.08	-3.16	60.19	3622.83
40	1940	667	-0.07	-3.23	- 54.81	3004.13
41	1941	864	0.05	-3.18	142.19	20217.99
42	1942	805	0.11	-3.07	83.19	6920.57
43	1943	589	-0.18	-3.25	-132.81	17638.49
44	1944	818	0.13	-3.12	96.19	9252.51
45	1945	610	-0.15	-3.27	-111.81	12501.47
46	1946	651	-0.10	-3.37	- 70.81	5014.05
47	1947	527	-0.27	-3.64	-194.81	37950.93
48	1948	727	0.01	-3.63	5.19	26.93
49	1949	751	0.04	-3.59	29.19	852.05
50	1950	727	0.01	-3.58	5.19	37950.73

Contd......

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51	1951	568.00	-0.21	-3.79	-153.81	23657.51
52	1952	618.00	-0.14	-3.93	-103.81	10776.51
53	1953	438.50	-0.39	-4.32	-283.31	80264.55
54	1954	810-80	0.12	-4.20	88.99	7919.22
55	1955	670.50	-0.07	-4.27	- 51.31	2632.71
56	1956	781.00	0.08	-4.18	59.19	3503.45
57	1957	415.60	-0.43	-5.11	-667.21	45169.18
58	1958	634.00	-0.12	-5.23	- 87.81	7710.59
59	1959	816.20	0.13	-5.10	94.39	8909.47
60	1960	795.70	0.10	-5.0	73.89	5459.73
61	1961	885.00	0.22	-4.78	163.19	26630.97
62	1962	618.20	-0.14	-4.92	-103.61	10735.03
63	1963	898.90	0.24	-4.68	177.09	31360.86
64	1964	901.40	0.24	-4.44	179.59	32252.56
65	1965	1106.30	0.53	-3.91	383.49	447832.56
66	1966	1162.30	0.61	-3.30	440.49	194031.44
67	1967	1222.80	0.69	-2.61	500.99	250990.98
68	1968	624.40	-0.13	-2.74	- 97.41	9488.70
69	1969	976.90	0.35	-2.39	255.09	65070.90
70	1970	681.10	-0.56	-2.95	- 40.71	1657.30
71	1971	1710.30	0.76	-2.28	488.49	238622.48
72	1972	1242.50	0.72	-1.56	520.69	27118.08
73	1973	1114.20	0.54	-1.02	392.39	153979.91
74	1974	950.50	0.31	-0.71	228.69	52299.11
75	1975	848.60	0.17	-0.54	126.79	16075.70
76	1976	905.00	0.25	-0.29	183.19	33558.57
77	1977	1000.00	0.78	0.49	569.19	323977.26
78	1978	822.91	0.14	0.63	101.10	10221.21
79	1979	884.20	0.22	0.85	162.39	26370.51
80	1980	772.80	0.07	0.92	50.99	2599.98
81	1981	575.80	-0.20	0.72	-146.01	21318.92
82	1982	1140.60	0.58	1.30	418.79	175385.06
83	1983	1084.52	0.50	1.80	362.71	131558.54
84	1984	456.35	0.36	1.44	-265.46	70469.01
85	1985	837.05	0.15	1.59	115.24	13280.25
86	1986	518.14	-0.28	1.31	-203.67	41481.46
87	1987	415.50	-0.42	0.89	-306.31	93825.8
88	1988	791.83	0.10	0.99	70.02	4902.80
89	1989	489.80	-0.32	0.67	-232.01	53828.64
90	1990	521.70	-0.27	0.40	-200.11	40044.01
91	1991	753.50	0.10	0.5	31.69	1004.25
92	1992	833.0	0.15	0.65	111.19	12363.21
93	1993	558.0	-0.22	0.43	-163.31	26833.71
		66965.40				4976305.90

Data Source: Board of Revenu, Lucknow, Uttar Pradesh.
Regional Meteriological Centre, New Delhi.

APPENDIX - I(B)

RAINFALL DATA ANALYSIS OF NOJHIL (MAT) RAIN GAUGE STATION

The mean of 93 years of Ranfall ($\bar{X}$) = 665.67 mm

The standard deviation = 288.54

The coefficient of variation = 43.34

S.No.	YEAR	ANNUAL RAINFALL X	DEPARTURE	CUMMULATIVE DEPARTMENT	$(X-\bar{X})$	$(X-\bar{X})^2$
1	1901	605	-0.10	-0.10	- 69.67	3680.84
2	1902	662	-0.00	-0.10	- 4.67	13.46
3	1903	805	0.21	0.11	+139.33	19412.84
4	1904	408	-0.38	-0.27	-257.67	66393.82
5	1905	999	0.58	0.23	+333.33	111108.89
6	1906	868	0.30	0.53	202.33	40937.42
7	1907	280	-0.57	-0.04	-385.67	148741.35
8	1908	578	-0.13	-0.17	- 87.67	7686.02
9	1909	383	-0.42	-0.59	-282.67	79902.32
10	1910	750	0.12	-0.47	+ 84.33	7111.54
11	1911	368	-0.44	-0.91	-297.67	88607.42
12	1912	988	0.48	-0.43	+322.33	103896.63
13	1913	476	-0.28	-0.71	-189.69	35974.70
14	1914	333	-0.50	-1.28	-332.67	110669.33
15	1915	691	0.03	-1.25	+ 25.33	641.60
16	1916	670	0.00	-1.25	4.33	18.74
17	1917	989	0.48	-0.77	+323.33	104542.29
18	1918	601	-0.09	-0.86	- 64.67	4182.20
19	1919	631	-0.05	-0.91	- 34.67	1202.01
20	1920	178	-0.73	-1.64	-487.67	47232.32
21	1921	883	0.32	-1.32	+217.33	47232.32
22	1922	801	0.20	-1.12	+135.33	18314.20
23	1923	629	-0.05	-1.17	- 36.60	1339.56
24	1924	275	-0.58	-1.75	-390.67	152623.05
25	1925	871	0.30	-1.45	+205.33	42160.40
26	1926	715	0.07	-1.38	+ 49.33	2433.44
27	1927	851	0.27	-1.11	+185.33	34347.20
28	1928	449	-0.32	-1.43	-216.67	46945.88
29	1929	507	-0.23	-1.66	-158.67	25176.16
30	1930	167	-0.74	-1.89	-498.67	248671.77
31	1931	630	-0.53	-2.42	- 35.67	1272.34
32	1932	814	0.22	-2.20	+148.33	22001.78
33	1933	534	-0.19	-2.39	-131.67	17336.98
34	1934	301	-0.54	-2.93	-364.67	132984.21
35	1935	536	-0.19	-3.12	-129.67	16814.30
36	1936	193	-0.70	-3.82	-472.67	223416.93
37	1937	113	-0.83	-4.65	-552.67	305444.13
38	1938	677	0.01	-4.64	+ 11.33	128.36
39	1939	901	0.35	-4.29	235.33	55380.20
40	1940	768	0.15	-4.14	102.33	10471.42
41	1941	194	-0.70	-4.84	-471.67	222472.59
42	1942	925	0.38	-4.46	+259.33	67252.50
43	1943	587	0.11	-4.35	- 78.67	6188.96
44	1944	613	-0.07	-4.42	- 52.67	2774.12
45	1945	651	-0.02	-4.44	- 14.67	215.20
46	1946	427	-0.35	-4.79	-238.67	56963.36
47	1947	452	-0.32	-5.11	-213.67	45654.86
48	1948	532	-0.20	-5.31	-133.67	17867.66
49	1949	263	-0.60	-5.91	-402.67	162143.13
50	1950	834	0.25	-5.66	+168.33	28334.98

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51	1951	377	-0.43	-6.09	-288.67	83330.36
52	1952	866	0.30	-5.79	200.33	40132.10
53	1953	438.4	-0.34	-6.13	-227.27	51651.65
54	1954	662.25	-0.00	-6.13	- 3.42	10.49
55	1955	856.30	0.28	-5.85	190.63	36339.79
56	1956	759.00	0.14	-5.57	93.33	8710.48
57	1957	480.00	-0.51	-6.46	-595.67	354822.75
58	1958	872.0	0.30	-6.16	206.33	42572.06
59	1959	790.0	0.18	-5.98	124.33	15457.94
60	1960	1296.0	0.94	-5.04	630.33	397315.91
61	1961	660.0	-0.00	-5.04	- 5.67	32.14
62	1962	618	-0.07	-5.11	- 47.67	2272.42
63	9163	816.0	0.22	-4.89	150.33	22599.10
64	1964	898.0	0.34	-4.55	232.33	53977.22
65	1965	1092	0.64	-3.91	426.33	181757.27
66	1966	1112.0	0.67	-3.24	446.33	199210.47
67	1967	1115	0.67	-2.57	449.33	201897.45
68	1968	624	-0.06	-2.63	- 41.67	1736.38
69	1969	896	0.34	-2.29	230.33	53051.90
70	1970	680	0.02	-2.27	14.33	205.33
71	1971	1310.0	0.96	-1.31	644.33	415161.15
72	1972	900.0	0.93	-0.38	624.33	389787.95
73	1973	1050.30	0.51	0.13	384.63	147940.24
74	1974	866	0.30	0.43	200.33	40132.10
75	1975	756	0.13	0.68	90.33	8159.50
76	1976	835.30	0.25	0.93	169.63	28774.33
77	1977	1115	0.67	1.35	449.33	201897.45
78	1978	886	0.33	1.68	220.33	48545.30
79	1979	974.20	0.46	2.14	308.53	95190.76
80	1980	817	0.22	2.36	151.33	22900.76
81	1981	925	0.38	2.74	259.33	67252.04
82	1982	685.2	0.02	2.76	19.53	381.42
83	1983	523	-0.21	2.53	-142.67	20354.72
84	1984	203	-0.69	1.84	-462.67	214063.53
85	1985	360.3	-0.45	1.39	-305.37	93250.83
86	1986	402.8	-0.39	1.00	-262.87	69100.63
87	1987	134.70	-0.79	0.21	-530.97	281929.14
88	1988	469	-0.29	-0.08	-196.67	38679.08
89	1989	129	-0.80	-0.88	-536.67	288014.69
90	1990	466.8	-0.29	-1.17	-198.87	39549.27
91	1991	269.5	-0.59	-0.176	-396.17	156950.67
92	1992	425	-0.36	-2.12	-240.67	57922.04
93	1993	362	-0.46	-2.98	-303.67	92215.46
		61603.85				

Data Source: Regional Meteriological Centre, New Delhi.

APPENDIX - II

Lithological logs of Boreholes Drilled by the State Tubewell Department in Yamuna-Karwan Sub-Basin

S.No.	Lithology	Depth Range (meters)	Thickness (meters)
LOCATION: CHITI			
TUBEWELL NO. 1			
1.	Surface clay	0.00 - 2.13	2.13
2.	Fine sand	2.13 - 9.44	7.31
3.	Fine sand & Bajri	9.44 - 18.28	8.84
4.	Fine to medium sand	18.28 - 24.38	6.10
5.	Medium sand & Kankar	24.38 - 27.43	3.05
6.	Medium sand to coarse sand with kankar	27.43 - 32.91	5.48
7.	Fine sand & kankar	32.91 - 36.57	3.66
8.	Clay & Kankar	36.57 - 38.40	1.83
9.	Fine sand & kankar	38.40 - 41.75	3.35
10.	Sandy clay & kankar	41.75 - 44.19	2.44
11.	Clay & kankar	44.19 - 46.02	1.83
12.	Clay kankar	46.02 - 50.59	4.58
LOCATION : SHAHPUR			
TUBEWELL No. 2			
1.	Suface clay	0.00 - 1.52	1.52
2.	Kankar	1.52 - 2.43	0.91
3.	Sandy clay	2.43 - 5.48	3.05
4.	Fine sand	5.48 - 7.92	2.44
5.	Clay	7.92 - 16.76	8.84
6.	Kankar	16.76 - 19.50	2.75
7.	Fine to medium sand	19.50 - 23.77	4.27
8.	Clay	23.77 - 32.30	8.54
9.	Fine to medium sand	32.30 - 39.62	7.32
10.	Medium sand	39.62 - 45.72	6.10
11.	Clay & kankar	45.72 - 66.44	20.73
12.	Fine sand & sand stone	66.44 - 71.62	5.18

13.	Clay & kankar	71.62 - 77.72	6.10
14.	Sticky clay	77.72 - 89.91	12.19
15.	Clay & kankar	89.91 -112.77	22.86
16.	Sandy clay	112.77 -118.87	6.10

LOCATION : DELEKHORD

TUBEWELL No. 3

1.	Surface clay	0.00 - 2.13	2.13
2.	Fine sand	2.13 - 6.40	4.27
3.	Clay	6.40 - 10.66	4.26
4.	fine sand	10.66 - 14.32	3.66
5.	Medium sand & kankar	14.32 - 16.76	2.44
6.	Course sand & Bajri	16.76 - 18.89	2.13
7.	Medium sand	18.89 - 22.25	3.36
8.	Fine to medium sand	22.25 - 26.51	4.27
9.	Hard clay & Kankar	26.51 - 30.17	3.66

LOCATION: RASULPUR

TUBEWELL No. 4

1.	Surface clay	0.00 - 3.04	3.04
2.	Kankar	3.04 - 6.09	3.05
3.	Clay & kankar	6.09 - 9.14	3.05
4.	Sandy clay	9.14 - 12.19	3.05
5.	Clays & Kankar	12.19 - 21.33	9.14
6.	Sandy clay	21.33 - 27.43	6.10
7.	Clay kankar	27.43 - 36.57	9.14
8.	Sandy clay	36.57 - 39.62	3.05
9.	Medium sand	39.62 - 45.72	6.10
10.	Clay kankar	45.72 - 47.24	1.52
11.	Medium sand & kankar	47.24 - 57.30	10.06
12.	Clay & kankar	57.30 - 60.65	3.05
13.	Medium sand & Sandstone	60.65 - 69.18	8.53
14.	Hard clay	69.18 - 76.20	7.02
15.	Fine to medium sand	76.20 - 82.90	6.70
16.	Hard clay & kankar	82.90 - 91.44	8.54

LOCATION : ALAMPUR

TUBEWELL No. 6

1.	Surface clay	0.00 - 3.96	3.96
2.	Clay	3.96 - 9.14	5.18
3.	Fine sand	9.14 - 12.19	3.05
4.	Clay	12.19 - 13.71	1.52
5.	Medium sand	13.71 - 17.67	3.96
6.	Clay	17.67 - 21.33	3.66
7.	Medium sand	21.33 - 45.11	23.78
8.	Clay	45.11 - 57.30	12.19
9.	Hard clay & kankar	57.30 - 70.40	13.10

LOCATION: BIJNANAGLA

TUBEWELL No. 6

1.	Surface clay	0.00 - 3.04	3.04
2.	Sandy clay	3.04 - 6.09	3.05
3.	Clay & kankar	6.09 - 27.43	21.34
4.	Fine sand	27.43 - 32.00	4.57
5.	Clay & kankar	32.00 - 41.14	9.14
6.	Fine sand	41.14 - 45.72	4.58
7.	Fine to medium sand	45.72 - 56.08	10.36
8.	Clay & kankar	56.08 - 62.48	6.40
9.	Fine to medium sand & sst	62.48 - 72.54	10.06
10.	Clay	72.54 - 77.72	5.18
11.	Fine sand	77.72 - 87.78	10.06
12.	Clay	87.78 - 91.44	3.66

LOCATION : PALSERA

TUBEWELL No. 7

1.	Surface clay	0.00 - 3.04	3.04
2.	Clay & kankar	3.04 - 18.28	15.24
3.	Fine sand	18.28 - 21.33	3.05
4.	Sand	21.33 - 22.86	1.53

5.	Fine sand & sand stone	22.86 - 27.43	4.57
6.	Clayd & kankar	27.43 - 32.00	4.57
7.	Fine sand	32.00 - 36.57	4.57
8.	Fine sand & sand stone	36.57 - 39.62	3.05
9.	Medium sand & Sandstone	39.62 - 44.50	4.88
10.	Clay & kankar	44.50 - 46.93	2.43
11.	Medium sand & sandstone	46.93 - 53.64	6.71
12.	Clay & kankar	53.64 - 57.30	3.66
13.	Medium sand & sandstone	57.30 - 64.00	6.70
14.	Clay	64.00 - 73.15	9.15
15.	Medium sand & sandstone	73.15 - 81.68	8.53
16.	Clay	81.68 - 88.39	6.71

LOCATION: TAPPAL

TUBEWELL No. 8

1.	Clay & kankar	0.00 - 15.24	15.24
2.	Hard clay	15.24 - 18.28	3.04
3.	Fine sand	18.28 - 24.38	6.10
4.	Medium sand	24.38 - 33.52	9.14
5.	Clay	33.52 - 36.57	3.05
6.	Medium sand & sandstone	36.57 - 47.85	11.28
7.	Hard clay	47.85 - 91.44	43.54
8.	Hard Clay & kankar	91.44 -109.72	18.28
9.	Clay	109.72 -149.35	39.63

LOCATION : NAGLA PADAM

TUBEWELL No. 9

1.	Surface clay	0.00 - 1.50	1.50
2.	Sandy clay & Kankar	1.50 - 6.09	4.59
3.	Medium sand	6.09 - 9.44	3.35
4.	Clay	9.44 - 16.15	6.71
5.	Fine sand	16.15 - 19.20	3.15
6.	Medium sand	19.20 - 21.94	2.74

7.	Coarse sand & kankar	21.94 - 35.05	13.11
8.	Fine sand	35.05 - 38.10	3.05
9.	Fine to medium sand	38.10 - 42.36	4.26
10.	Clay & kankar	42.36 - 57.42	15.06

LOCATION : NAGLA JARELA

WELL No. 10

1.	Surface clay	0.00 - 3.04	3.04
2.	Clay & kankar	3.04 - 4.26	1.22
3.	Fine sand	4.26 - 9.14	4.88
4.	Medium sand	9.14 - 12.49	3.35
5.	Coarse sand	12.49 - 15.24	2.75
6.	Clay & kankar	15.24 - 19.20	3.96

LOCATION : JAMUNKA

TUBEWELL No. 12

1.	Surface clay	0.00 - 3.04	3.04
2.	Clay & kankar	3.04 - 7.62	4.58
3.	Fine sand	7.62 - 10.36	2.75
4.	Clay	10.36 - 12.19	1.83
5.	Sand & kankar	12.19 - 16.45	4.26
6.	Clay & kankar	16.45 - 19.50	3.05
7.	Fine sand & sand stone	19.50 - 28.95	9.45
8.	Clay & kankar	28.95 - 32.30	3.35
9.	Fine sand	32.30 - 35.35	3.05
10.	Fine sand & sandstone	35.35 - 41.45	6.10
11.	Fine to medium sand	41.45 - 45.72	4.37
12.	Sandy clay & kankar	45.72 - 48.76	3.04
13.	Clay & kankar	48.76 - 65.0	23.78
14.	Clay		

LOCATION : UMRI

TUBEWELL NO. 11

1.	Surface clay	0.00 - 3.04	3.04
2.	Clay	3.04 - 8.53	5.49
3.	Fine sand	8.53 - 12.19	3.66
4.	Fine sand & sandstone	12.19 - 14.32	2.13
5.	Clay & kankar	14.32 - 18.89	4.57
6.	Fine sand	18.89 - 21.94	3.05
7.	Sand with kankar	21.94 - 27.12	5.18
8.	Sand & Gravel	27.12 - 29.56	2.44
9.	Fine sand	29.56 - 45.72	16.16
10.	Fine sand to medium	45.72 - 47.85	2.13
11.	Clay & kankar	47.85 - 60.35	12.50
12.	Fine sand & sandstone	60.35 - 68.88	8.53
13.	Soft clay	68.88 - 73.15	4.27

LOCATION : RESRI

TUBEWELL No. 14

1.	Surface clay	0.00 - 2.13	2.13
2.	Fine sand	2.13 - 8.22	6.09
3.	Soft clay & kankar	8.22 - 19.20	10.98
4.	Fine sand & kankar	19.20 - 21.33	2.13
5.	Hard clay	21.33 - 26.21	4.88
6.	Fine sand	26.21 - 27.12	0.91
7.	Clay & kankar	27.12 - 31.39	4.27
8.	Fine sand	31.39 - 39.62	8.23

LOCATION : NAGLASU

TUBEWELL No. 15

1.	Surface clay	0.00 - 3.35	3.35
2.	Sandy clay & kankar	3.35 - 5.48	2.13
3.	Clay	5.48 - 10.66	5.18
4.	Fine sand & kankar	10.66 - 12.80	2.14
5.	Medium sand	12.80 - 16.15	3.35

6.	Soft clay & kankar	16.15 - 20.11	3.96
7.	Fine sand & kankar	20.11 - 22.86	2.75
8.	Fine sand	22.86 - 26.51	3.65
9.	Hard clay & kankar	26.61 - 30.17	3.66
10.	Fine sand	30.17 - 34.74	4.57
11.	Hard clay	34.74 - 37.49	2.75

LOCATION: MANPUR
TUBEWELL NO. 16

1.	Surface clay	0.00 - 3.04	3.04
2.	Yellow sand	3.04 - 6.09	3.05
3.	Clay & kankar	6.09 - 13.41	7.32
4.	Fine sand	13.41 - 16.45	3.04
5.	Medium sand & kankar	16.45 - 17.98	1.53
6.	Hard clay & kankar	17.98 - 20.72	2.74
7.	Fine sand	20.72 - 23.77	3.05
8.	Coarse sand with kankar	23.77 - 29.87	6.10
9.	Clay & kankar	29.87 - 32.91	3.04
10.	Fine sand with kankar	32.91 - 40.84	7.93
11.	Clay & kankar	40.84 - 43.89	3.05

LOCATION : NAGLA SADA
TUBEWELL No. 17

1.	Surface clay	0.00 - 2.74	2.74
2.	Clay & kankar	2.74 - 3.96	1.22
3.	Fine sand	3.96 - 5.48	1.52
4.	Clay	5.48 - 8.53	3.05
5.	Clay & kankar	8.53 - 12.80	4.27
6.	Fine sand	12.80 - 14.32	15.25
7.	Soft clay & kankar	14.32 - 18.89	4.57
8.	Fine sand	18.89 - 21.94	3.05
9.	Fine sand & kankar	21.94 - 26.82	4.88
10.	Hard clay	26.82 - 31.69	4.87

LOCATION : NAGOLA
TUBEWELL NO. 18

1.	Surface clay	0.00 - 2.74	2.74
2.	Sandy clay	2.74 - 6.09	3.35
3.	Fine sand	3.35 - 7.01	3.66
4.	Clay Hard	7.01 - 12.49	5.48
5.	Fine sand	12.48 - 14.63	2.15
6.	Clay & kankar	14.63 - 23.46	8.83
7.	Fine sand	23.46 - 27.12	3.66

LOCATION: BAROLA
TUBEWELL No. 19

1.	Clay	0.00 - 1.82	1.82
2.	Fine sand	1.82 - 3.96	2.14
3.	Sandy clay	3.96 - 8.22	4.26
4.	Clay & kankar	8.22 - 11.88	3.66
5.	Fine sand	11.88 - 14.63	2.75
6.	Clay & kankar	14.63 - 21.33	6.70
7.	Fine sand & kankar	21.33 - 27.73	6.40
8.	Hardclay & kankar	27.73 - 31.69	3.96

LOCATION : KASISON
TUBEWELL No. 21

1.	Surface clay	0.00 - 3.04	3.04
2.	Clay & kankar	3.04 - 7.31	4.27
3.	Clay	7.31 - 12.19	4.88
4.	Fine sand	12.19 - 14.02	1.83
5.	Clay & kankar	14.02 - 15.84	1.82
6.	Clay	15.84 - 19.20	3.36
7.	Fine sand & sandstone	19.20 - 27.12	7.92
8.	Clay & kankar	27.12 - 35.66	8.54
9.	Fine sand	35.66 - 38.10	2.44
10.	Clay & kankar	38.10 - 40.53	2.43

11.	Medium sand	40.53 - 43.28	2.75
12.	Clay & kankar	43.28 - 52.42	9.14
13.	Fine sand & sand stone	52.42 - 53.94	1.52
14.	Medium sand	53.94 - 60.96	7.02
15.	Coarse sand	60.96 - 66.44	5.48
16.	Clay	66.44 - 72.54	6.10
17.	Medium sand	72.54 - 74.98	2.44
18.	Medium coarse sand	74.98 - 79.85	4.87
19.	Coarse sand & gravel	79.85 - 88.39	8.54
20.	Clay	88.39 - 91.44	3.05

LOCATION : BAZIDPUR

TUBEWELL No. 22

1.	Surface clay	0.00 - 3.04	3.04
2.	Clay & kankar	3.04 - 18.28	15.24
3.	Hard clay	18.28 - 21.33	3.05
4.	Clay & kankar	21.33 - 32.61	11.28
5.	Fine sand	32.61 - 35.66	3.05
6.	Fine sand & sandstone	35.66 - 46.63	10.97
7.	Hard clay	46.63 - 49.68	3.05
8.	Clay & kankar	49.68 - 55.16	5.48
9.	fine sand & sandstone	55.16 - 67.05	11.89
10.	Hard clay	67.05 - 71.93	4.88

LOCATION : SABALPUR

TUBEWELL No. 26

1.	Clay	0.00 - 3.04	3.04
2.	Fine sand	3.04 - 9.14	6.10
3.	Fine sand & kankar	9.14 - 19.81	10.67
4.	Sand & Kankar	19.81 - 21.33	1.52
5.	Hard clay & kankar	21.33 - 25.90	4.57
6.	Sand & Kankar	25.90 - 36.57	10.67
7.	Clay & kankar	36.57 - 52.42	15.85
8.	Fine sand	52.42 - 53.64	1.22
9.	Clay & kankar	53.64 - 56.08	2.44
10.	Fine sand	56.08 - 60.96	4.88

LOCATION : PISAWAN

TUBEWELL No. 27

1.	Surface clay	0.00 - 2.43	2.43
2.	Sandy clay	2.43 - 3.96	1.53
3.	Fine sand	3.96 - 5.79	1.83
4.	Clay	5.79 - 7.31	1.52
5.	Sandy clay	7.31 - 11.58	4.27
6.	Clay	11.58 - 13.71	2.13
7.	Coarse sand & kankar	13.71 - 16.76	3.05
8.	Clay & kankar	16.76 - 19.50	2.74
9.	Fine sand & kankar	19.50 - 22.86	3.36
10.	Fine sand	22.86 - 27.43	4.57
11.	Medium sand & kankar	27.43 - 28.95	1.52
12.	Clay with kankar	28.95 - 33.22	4.27

LOCATION : GOMAT

TUBEWELL No. 28

1.	Fine sand	0.00 - 8.53	8.53
2.	Clay & kankar	8.53 - 10.66	2.13
3.	Fine sand	10.66 - 12.19	1.53
4.	Soft clay & kankar	12.19 - 16.76	4.57
5.	Hard clay & kankar	16.76 - 21.64	4.88
6.	Fine sand & kankar	21.64 - 30.78	9.74

LOCATION : PALSERA

TUBEWELL No. 29

1.	Clay	0.00 - 9.14	9.14
2.	Fine sand	9.14 - 12.19	3.05
3.	Clay	12.19 - 18.28	6.09
4.	Clay & kankar	18.28 - 21.33	3.05
5.	Sandy clay	21.33 - 36.57	15.24
6.	Clay & kankar	36.57 - 39.62	3.05

7.	Fine to medium sand	39.62 - 45.72	6.10
8.	Medium to coarse sand	45.72 - 48.76	3.05
9.	Coarse sand	48.76 - 51.85	3.05
10.	Medium sand & sand stone	51.85 - 54.86	3.05
11.	Clay & kankar	54.86 - 60.96	6.10
12.	Medium sandstone	60.96 - 67.05	6.10
13.	Medium to coarse sand	67.05 - 73.15	6.10
14.	Clay	73.15 - 79.24	6.10
15.	Medium sand	79.24 - 85.34	6.10
16.	Clay	85.34 - 91.44	6.10

LOCATION: MAUR

TUBEWELL No. 31

1.	Surface clay	0.00 - 3.05	3.05
2.	Fine sand	3.05 - 45.41	42.36
3.	Medium to coarse sand	45.41 - 49.37	3.96
4.	Clay & kankar	49.37 - 73.15	23.78
5.	Clay	73.15 - 80.16	7.01
6.	Sandy clay	80.16 - 86.25	6.09
7.	Clay & kankar	86.25 -108.20	21.95
8.	Sandy clay & kankar	108.20 -137.16	28.96
9.	Clay & kankar	137.16 -152.40	15.24

LOCATION : HAMIDPUR

TUBEWELL NO. 33

1.	Surface clay	0.00 - 3.05	3.05
2.	Fine sand	3.05 - 6.10	3.05
3.	Clay	6.10 - 12.19	6.09
4.	Fine to medium sand	12.19 - 15.24	3.05
5.	Clay	15.24 - 21.33	6.09
6.	Fine to medium sand	21.33 - 27.43	6.10
7.	Poor fine sand	27.43 - 42.67	15.24
8.	Fine to medium sand	42.67 - 45.72	3.05
9.	Hard clay	45.72 - 70.76	25.04

LOCATION : BASERA

TUBEWELL No. 34

1.	Surface clay	0.00 - 3.05	3.05
2.	Kankar	3.05 - 6.10	3.05
3.	Fine sand	6.10 - 9.14	3.05
4.	Sandy clay with kankar	9.14 - 12.19	3.05
5.	Clay	12.19 - 22.86	10.67
6.	Fine sand	22.86 - 27.43	4.57
7.	Clay & kankar	27.43 - 36.57	9.14
8.	Clay	36.57 - 39.62	3.05
9.	Medium sand & sand stone	39.62 - 45.72	6.10
10.	Fine sand & sand stone	45.72 - 48.76	3.04
11.	Medium sand & sand stone	48.76 - 60.96	12.20
12.	Clay & kankar	60.96 - 76.20	15.24

LOCATION : JALGARHI

TUBEWELL No. 35

1.	Surface clay	0.00 - 3.05	3.05
2.	Kankar	3.05 - 6.10	3.05
3.	Clay & kankar	6.10 - 12.19	6.09
4.	Clay	12.91 - 15.24	3.05
5.	Clay & kankar	15.24 - 36.57	21.33
6.	Fine to medium sand	36.57 - 44.80	8.23
7.	Clay & kankar	44.80 - 51.81	7.01
8.	Fine sand & sand stone	51.81 - 54.86	3.05
9.	Clay & kankar	54.86 - 57.91	3.05
10.	Clay	57.91 - 59.43	1.52
11.	Fine sand to medium sand stone	59.43 - 80.77	21.33

LOCATION : JAHANGARHI

TUBEWELL No. 36

1.	Surface clay	0.00 - 3.05	3.05
2.	Fine sand with kankar	3.05 - 9.15	6.10
3.	Clay	9.14 - 15.24	6.10
4.	Kankar	15.24 - 18.28	3.04
5.	Fine sand with sand stone	18.28 - 27.43	9.15
6.	Medium sand with sand stone	27.43 - 42.67	15.24
7.	Clay with kankar	42.67 - 48.76	6.09
8.	Clay	48.76 - 51.81	3.05
9.	Clay with kankar	51.81 - 91.44	39.63

LOCATION : JALALPUR

TUBEWELL No. 37

1.	Surface clay	0.00 - 3.65	3.65
2.	Clay & kankar	3.65 - 8.83	5.18
3.	Clay	8.83 - 13.41	4.58
4.	Clay & kankar	13.41 - 20.72	7.31
5.	Fine sand & sand stone	20.72 - 30.78	10.06
6.	Clay & Kankar	30.78 - 35.96	5.18
7.	Fine sand	35.96 - 38.40	2.44
8.	Fine sand & sand stone	38.40 - 42.67	4.27
9.	Fine to medium snad	42.67 - 48.76	6.09
10.	Medium sand & Kankar	48.76 - 55.16	6.40
11.	Clay & kankar	55.16 - 56.99	31.83

LOCATION : SABALPUR

TUBEWELL No. 56

1.	Surface clay	0.00 - 1.52	1.52
2.	Sandy clay	1.52 - 18.28	16.76
3.	Fine sand	18.28 - 25.90	7.62

4.	Clay kankar	25.90 - 42.67	16.77
5.	Fine to medium sand	42.67 - 48.15	5.48
6.	Sandy clay	48.15 - 52.42	4.27
7.	Fine to medium sand	52.42 - 57.91	5.49
8.	Medium sand	57.91 - 88.39	30.48
9.	Clay kankar	88.39 -100.58	12.19

LOCATION : AMARGARHI

TUBEWELL No. 58

1.	Surface clay	0.00 - 6.10	6.10
2.	Poor fine sand	6.10 - 24.40	18.30
3.	Fine sand	24.40 - 30.50	6.10
4.	fine to medium sand	30.50 - 48.80	18.30
5.	Fine sand	48.80 - 61.00	12.20
6.	Fine to medium sand	61.00 - 79.30	18.30
7.	Clay & kankar	79.30 - 85.40	6.10
8.	fine to medium sand	85.40 - 97.60	12.20
9.	Clay & kankar	97.60 -122.00	24.40

LOCATION : MAHIGAURA

TUBEWELL No. 25

1.	Surface	0.00 - 6.10	6.10
2.	Fine sand	6.10 - 30.50	24.40
3.	Fine to medium sand	30.50 - 36.60	6.10
4.	Medium sand	36.60 - 48.80	12.20
5.	Medium sand & sand stone	48.80 - 67.00	18.20
6.	Clay	67.00 - 74.00	7.00
7.	Fine sand	74.00 - 80.10	6.10
8.	Clay & kankar	80.10 - 96.90	16.80
9.	Fine to medium sand	96.90 -122.80	25.90
10.	Fine sand	122.80 -125.90	3.10
11.	Clay & kankar	125.90 -128.90	3.00

LOCATION : WAINA

TUBEWELL No. 32

1.	Clay	0.00 - 7.65	7.65
2.	Fine sand	7.65 - 12.50	4.85
3.	Clay	12.50 - 16.00	3.50
4.	Fine to medium sand and kankar	16.00 - 25.20	9.20
5.	Clay	25.20 - 33.50	8.30
6.	Fine sand	33.50 - 47.00	13.50
7.	Clay to sticky clay	47.00 - 54.00	7.00

LOCATION : SOPHA

TUBEWELL No. 60

1.	Clay	0.00 - 9.80	9.80
2.	Fine sand	9.80 - 12.70	2.90
3.	Sand fine with kankar	12.70 - 15.70	3.00
4.	Clay & kankar	15.70 - 19.17	3.47
5.	Clay	19.17 - 25.04	5.87
6.	Clay & kankar	25.04 - 37.59	12.55
7.	Sand & kankar	37.59 - 40.84	3.25
8.	Clay and Kankar	40.84 - 82.23	41.39
9.	Sand with kankar	82.23 - 85.23	3.00
10.	Clay with kankar	85.23 -240.00	154.77

LOCATION : MUSMANA

TUBEWELL No. 40

1.	Top soil	0.00 - 1.20	1.20
2.	Silty clay with fine sand	1.20 - 7.20	6.00
3.	silty grey with clay	7.20 - 9.50	2.30
4.	Fine sand with clay and kankar	9.50 - 13.50	4.00
5.	Fine sand with silty clay	13.50 - 15.00	1.50
7.	Medium sand grey	15.00 - 21.50	6.50
7.	Coarse sand with kankar	21.50 - 25.50	4.00

LOCATION : CHINPARAI

TUBEWELL No. 41

1.	Top soil	0.00 - 1.50	1.50
2.	Clayey silt with fine sand	1.50 - 4.20	2.70
3.	silt and clay grey	4.20 - 8.60	4.40
4.	Clayey silt with kankar	8.60 - 13.90	5.30
5.	Fine sand	13.90 - 17.40	3.50
6.	Fine clay with kankar	17.40 - 22.00	4.60
7.	Medium sand	22.00 - 24.00	2.00

LOCATION : PARSAULI

TUBEWELL NO. 42

1.	Top soil	0.00 - 1.50	1.50
2.	Clayey silt with fine sand	1.50 - 4.50	3.00
3.	Clayey silt, grey with kankar	4.50 - 13.50	9.00
4.	Fine sand and silt	13.50 - 18.00	4.50
5.	Fine clay with little kankar	18.00 - 21.50	3.50
6.	Medium to coarse sand	21.50 - 23.50	2.00

LOCATION : ADDA

TUBEWELL No. 43

1.	Top soil	0.00 - 1.50	1.50
1.	Clayey silt and sand sand	1.50 - 6.30	4.80
3.	Clay grey with sand and silt	6.30 - 9.50	3.20
4.	Fine sand	9.50 - 13.50	4.00
5.	Clayey grey	13.50 - 18.75	5.25
6.	Medium sand	18.75 - 20.25	1.50

LOCATION : NAOLI

TUBEWELL No. 44

1.	Top soil	0.00 - 1.50	1.50
2.	Clayey silt and sand	1.50 - 5.40	3.90
3.	Clay grey and silt	5.40 - 9.60	4.20
4.	Silty sand and kankar	9.60 - 13.40	3.80
5.	Clay grey	13.40 - 17.65	4.25
6.	Fine sand	17.65 - 19.65	2.00
7.	Clay and silt	19.65 - 24.00	4.35
8.	Fine to medium sand	24.00 - 25.50	1.50

LOCATION : SURIR

TUBEWELL No. 45

1.	Top soil	0.00 - 1.50	1.50
2.	Clayey silt and fine sand	1.50 - 7.20	5.70
3.	Silt clay grey and fine sand	7.20 - 10.60	3.40
4.	Silt and sand with kankar	10.60 - 14.80	4.20
5.	Fine to medium sand	14.80 - 18.55	3.75
6.	Clay grey	18.55 - 25.20	6.65
7.	Medium sand	25.20 - 26.50	1.30

LOCATION : MANAGARHI

TUBEWELL No. 47

1.	Top soil	0.00 - 1.50	1.50
2.	Clayey silt with sand	1.50 - 4.50	3.00
3.	Silt grey with clay	4.50 - 7.70	3.20
4.	Fine sand and silt	7.70 - 10.10	2.40
5.	Fine clay and silt	10.10-12.25	2.15
6.	Fine sand	12.25-18.50	6.25
7.	Fine clay grey	18.50 - 21.00	2.50
8.	Medium to coarse sand	21.00 - 23.50	2.50

LOCATION: VIJAIGARHI
TUBEWELL NO. 48

1.	Top soil	0.00 - 1.30	1.30
2.	Clayey silt and kankar	1.30 - 3.00	1.70
3.	Silt and clay grey	3.00 - 5.00	2.00
4.	Fine sand and silt with little clay	5.00 - 8.50	3.50
5.	Fine sand and silt sith little kankar	8.50 - 12.50	4.00
6.	Grey clay with little silt	12.50 - 17.00	4.50
7.	Medium sand and silt	17.00 - 18.50	1.50
8.	Coarse Jamuna sand	18.50 - 33.50	15.00

LOCATION : KULANA
TUBEWELL No. 49

1.	Top soil	0.00 - 1.60	1.60
2.	Clayey silt with fine sand	1.60 - 2.20	0.80
3.	Silt grewy with clay and fine sand	2.20 - 5.20	3.00
4.	Fine sand and kankar	5.20 - 7.70	2.50
5.	Medium to fine sand	7.70 - 19.15	11.45
6.	Fine sand and kankar	19.15 - 25.50	6.35
7.	Medium to coarse sand and kankar	25.50 - 30.00	4.50

LOCATION : BHALAL
TUBEWELL No. 50

1.	Top soil	0.00 - 1.00	1.00
2.	Hard kankar and clay	1.00 - 2.00	1.00
3.	Clayey silt	2.00 - 3.00	1.00
4.	Yellowisyh grey sand	3.00 - 6.00	3.00
5.	Medium sand and kankar	6.00 - 10.00	4.00

LOCATION : JARARA

TUBEWELL No. 46

1.	Top soil	0.00 - 1.20	1.20
2.	Clayey silt and sand	1.20 - 2.30	1.10
3.	Silt grey with clay	2.30 - 4.80	2.50
4.	Fine sand with kankar	4.80 - 8.20	3.40
5.	Fine sand with silt	8.20 - 11.95	3.75
6.	Clay grey	11.95 - 17.25	5.30
7.	Fine to medium sand	17.25 - 18.50	1.25

LOCATION : NOHJHIL

TUBEWELL No. 46

1.	Top soil	0.0 - 1.64	1.64
2.	Silt grey with clay	1.64 - 6.56	4.92
3.	Clay grey and silt with a little kankar	6.56 - 13.77	7.21
4.	Kankar with sand	13.77 - 34.77	21.00
5.	Kankar hard with clay and sand	34.77 - 47.24	12.47
6.	Clay sticky buff with a little kankar	47.24 - 50.52	3.28
7.	Clay buff with less of kankar	50.52 - 71.52	21.00
8.	Clay sticky buff with very little kankar	71.52 - 76.77	5.25
9.	Clay sticky buff with kankar	76.77-82.34	5.57

LOCATION: DAULATPUR

TUBEWELL No. 59

1.	Top soil	0.00 - 1.65	1.65
2.	Silty clay with fine sand	1.65 - 5.50	3.85
3.	Silty clay	5.50 - 10.00	4.50
4.	Silty sand with kankar	10.00 - 14.50	4.50
5.	Medium sand and silt	14.50 - 20.50	6.00
6.	Clay with little silt	20.50 - 24.00	3.50

APPENDIX - III

Hydrogeological data of Dugwells Inventoried in the Yamuna - Karwan Sub-basin in parts of Aligarh-Mathura Districts.
(June 1992 - November 1992)

Sl. No.	Location	Diameter (M)	Height of M.P. (AGL) (M)	Total Depth of the well (M)	R.L. of M.P. (M)	Pre-Monsoon Date	Pre-Monsoon Depth of water B.M.P. (M)	Pre-Monsoon D.T.W. B.G.L. (M)	Pre-Monsoon W.L. a.m.s.l. (M)	Post-Monsoon Date	Post-Monsoon D.T.W. B.M.P. (M)	Post-Monsoon D.T.W. B.G.L. (M)	Post-Monsoon W.L. a.m.s.l. (M)	water level fluctuation (m)	Temp.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.	Khair	1.90	0.40	12.20	190.01	4.6.92	11.30	10.90	178.71	5.11.92	10.95	10.55	179.06	0.35	22°C
2.	Baloria	1.50	0.75	12.00	188.75	"	DRY	DRY	-	"	10.60	9.85	178.15	-	"
3.	Bhadera	2.75	0.60	13.00	187.60	"	DRY	DRY	-	"	12.70	12.10	174.90	-	"
4.	Palchand	3.40	1.00	11.30	191.00	"	10.70	9.70	180.30	"	9.45	8.45	181.55	1.25	"
5.	Nisuja	3.30	0.50	12.60	188.50	"	10.30	9.80	178.20	"	9.00	8.50	179.50	0.50	"
6.	Arni	2.50	1.50	12.20	193.50	"	10.90	9.40	182.60	"	9.60	8.10	183.90	1.30	"
7.	Nayabas	2.00	0.75	6.70	184.95	"	6.00	5.25	178.95	"	5.15	4.40	179.80	0.85	"
8.	Khairasattu	3.50	0.10	8.60	189.10	"	5.20	5.10	183.90	"	3.70	3.60	185.40	1.50	"
9.	Edalpur	2.40	0.65	5.80	190.65	"	4.85	4.20	185.80	"	3.00	2.35	187.65	1.85	"
10.	Mayaramgarhi	2.70	1.00	4.45	188.00	"	2.20	1.20	177.80	"	1.90	0.90	186.10	0.30	"
11.	Sajnan	3.00	1.00	9.95	189.00	"	9.10	8.10	179.90	"	7.90	6.90	181.10	1.20	"
12.	Manpur	1.00	0.25	4.12	187.25	"	3.15	2.90	184.10	"	2.15	1.90	185.10	1.00	"
13.	Ahrola	2.00	2.00	6.35	193.00	"	4.60	2.60	188.40	"	4.00	2.00	189.00	0.60	"
14.	Shiwala Kalan	3.00	0.50	6.45	189.00	"	4.75	4.25	184.25	"	3.95	3.45	185.05	0.80	21°C
15.	Shiwala Khurd	3.00	0.50	8.50	188.50	"	4.00	3.50	184.50	"	3.13	2.63	185.37	0.87	"
16.	Mathna	4.00	0.30	9.60	187.30	5.6.92	8.20	7.90	179.10	6.11.92	7.30	7.00	180.00	0.90	"
17.	Madannpur	2.50	1.50	7.00	185.50	"	5.50	4.00	180.00	"	4.20	2.70	181.30	1.30	"
18.	Nagla	1.25	1.00	6.00	181.00	"	2.90	1.90	178.10	"	2.45	1.45	178.55	0.45	"
19.	Sujanpur	3.70	1.25	10.35	190.25	"	4.45	3.20	185.80	"	3.70	2.45	186.55	0.75	"
20.	Sujanpur-Khair Road	1.45	0.80	6.40	186.80	"	5.10	4.30	181.70	"	4.10	3.30	182.70	1.00	"
21.	Gomat	3.0	0.40	8.35	184.40	"	7.50	7.30	176.90	"	6.10	5.70	178.30	1.40	"
22.	Khera	3.0	1.0	9.50	190.0	"	5.76	4.76	184.24	"	4.91	3.91	185.09	0.85	"
23.	Narainpur	1.25	1.25	6.95	188.25	"	6.00	4.75	182.25	"	3.90	2.65	184.35	2.10	25°C
24.	Takipur	1.75	1.0	7.90	189.58	"	6.35	5.35	183.23	"	4.20	3.20	185.38	2.15	"
25.	Baluapur	2.50	0.70	8.90	187.70	"	6.50	5.80	181.20	"	4.45	3.75	183.25	2.05	"
26.	Karanpur	3.00	1.00	10.95	186.00	"	10.10	9.10	175.90	"	8.80	7.80	177.20	1.30	"
27.	Salpur	2.75	0.75	14.40	186.75	"	14.00	13.25	172.75	"	12.35	11.60	174.40	1.65	"
28.	Dajyadpur	3.00	1.25	14.60	187.25	"	14.40	13.15	172.85	"	12.25	11.00	175.00	2.15	"
29.	Nagolia	4.00	0.20	16.00	191.20	7.6.92	15.35	15.15	175.85	7.11.92	14.40	14.20	176.80	0.95	"
30.	Gutraula	2.00	1.50	17.00	196.50	"	DRY	DRY	-	"	15.70	14.20	180.80	-	"
31.	Ghagauli	2.00	1.00	20.80	191.00	"	20.00	19.00	171.00	"	19.30	18.30	171.70	0.70	"
32.	Simrauti	4.00	0.80	10.50	190.80	"	10.30	9.50	180.50	"	8.85	8.05	181.95	1.45	"
33.	Udaipur	2.00	1.20	13.70	185.20	"	12.85	11.65	172.35	"	10.35	9.15	174.85	2.50	"
34.	Tappal	4.5	2.50	10.90	198.76	"	9.80	7.30	188.96	"	7.45	4.95	191.31	2.35	"
35.	Nurpur	1.50	1.00	10.80	182.00	"	9.50	8.50	172.50	"	8.70	7.70	173.30	0.80	25°C
36.	Adampur	2.25	1.50	6.90	181.10	"	5.60	4.10	175.50	"	5.15	3.65	175.95	0.45	"
37.	Mahabalipur	1.50	1.00	8.30	183.60	"	6.75	5.75	176.85	"	6.17	5.17	177.43	0.58	"
38.	Ghartara	2.00	1.00	10.50	184.10	"	6.22	5.22	177.88	"	5.83	4.83	178.27	0.39	"
39.	Pipli	2.00	0.80	9.50	185.60	"	8.40	7.60	177.20	"	7.30	6.50	178.30	1.10	"
40.	Raipur	1.25	1.20	6.40	184.20	8.6.92	6.02	4.85	178.15	8.11.92	5.35	4.15	178.85	0.70	"
41.	Hamidpur	2.50	0.80	10.60	191.80	"	10.00	9.20	181.80	"	9.38	8.58	182.42	0.62	"
42.	Sarai	2.00	1.40	11.55	188.40	"	10.10	8.70	178.30	"	9.15	7.75	179.25	0.95	"
43.	Budhaka	2.00	0.50	7.70	194.50	"	5.45	4.95	189.05	"	4.80	4.30	189.70	0.65	"
44.	Attai	1.20	1.40	6.80	194.40	"	3.60	2.20	190.80	"	2.88	1.48	191.52	0.72	"
45.	Nagla Kurana	3.00	0.90	11.90	191.90	"	10.85	9.95	181.05	"	10.43	9.53	181.47	0.42	"

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
46.	Jattari	3.00	0.50	13.0	195.47	8.6.92	DRY	DRY	-	8.11.92	11.50	-	193.92	-	-
47.	Nagla Padam	2.25	1.20	15.95	193.20	"	15.55	14.35	177.65	"	14.0	12.80	179.20	1.55	
48.	Sopna	0.80	0.40	7.40	188.65	"	5.83	5.43	182.82	"	5.32	4.92	183.33	0.51	
49.	Rajpur	2.00	0.50	5.55	193.50	"	5.05	4.55	188.45	"	4.44	3.94	189.06	0.61	
50.	Amargarhi	3.00	1.00	6.60	194.00	"	4.90	3.90	189.10	"	3.85	2.85	190.15	1.05	24°C
51.	Balulpur	3.00	1.50	9.80	191.50	"	5.50	4.00	186.00	"	4.82	3.32	186.68	0.68	
52.	Nagla Bijna	3.00	1.00	9.40	193.00	"	5.55	4.55	187.45	"	4.97	3.97	188.03	0.58	
53.	Shadipur	1.00	0.50	6.65	193.00	"	5.35	4.85	187.65	"	5.04	4.54	187.96	0.31	
54.	Kara	2.50	1.25	5.90	193.25	"	5.30	4.05	187.95	"	4.85	3.60	188.40	0.45	
55.	Mirpur Dhara	2.25	1.00	10.40	194.00	"	9.30	8.30	184.70	"	8.20	7.20	185.80	1.10	
56.	Paspi	3.50	0.25	8.20	194.25	"	DRY	DRY	-	"	8.10	-	186.75	-	
57.	Pisawan	1.75	0.40	14.70	196.19	10.6.92	13.10	12.70	183.09	10.11.92	10.80	10.40	185.39	2.30	22°C
58.	Mahijaura	3.00	0.90	17.00	196.90	"	16.50	15.60	180.40		15.15	14.25	181.75	1.35	
59.	Sabalpur	1.75	1.10	14.55	196.10	"	14.32	13.22	181.78	"	13.17	12.07	182.93	1.15	
60.	Chiti	3.00	0.30	14.65	195.30	"	14.35	14.05	180.95	"	13.37	13.07	181.93	0.98	
61.	Alampur	3.50	0.70	13.55	194.70	"	12.45	11.75	182.25	"	10.37	9.67	184.33	2.08	
62.	Jamunaka	4.00	0.50	12.10	190.50	"	12.00	11.50	178.50	"	10.02	9.52	180.48	1.98	
63.	Rasulpur	1.45	1.10	9.70	193.10	"	7.45	6.35	185.65	"	6.60	5.50	186.50	0.85	
64.	Jartauli	1.50	0.70	11.20	187.20	"	9.37	8.67	177.83	"	8.20	7.52	179.00	1.15	
65.	Udaigarhi	2.50	1.00	9.00	184.70	"	6.00	5.00	178.70	"	4.87	3.87	179.83	1.13	
66.	Edalgarhi	1.75	1.25	7.30	184.50	"	6.20	4.95	178.30	"	5.18	3.93	179.32	1.02	
67.	Bajna	3.00	1.50	10.75	184.71	"	10.15	8.65	174.56	"	9.60	8.10	175.11	0.55	
68.	Parsauli	3.00	1.60	12.30	184.00	"	9.15	7.55	174.85	"	7.86	6.26	176.14	1.29	
69.	Baraut	2.00	1.00	12.25	182.52	"	11.30	10.30	171.22	"	10.85	9.85	171.67	0.45	
70.	Bahlal	1.50	1.75	13.45	180.00	"	12.75	11.00	167.25	"	11.45	9.70	168.55	1.30	
71.	Surir	3.50	1.00	15.50	182.71	12.6.92	11.10	10.10	171.61	12.11.92	9.35	8.35	173.36	1.75	
72.	Nojhil	1.30	3.50	20.20	180.0	"	18.85	15.35	161.15	"	18.35	14.85	161.65	0.50	
73.	Chinpari	1.30	1.00	7.70	179.50	"	6.90	5.90	172.60	"	6.18	5.18	173.32	0.72	21°C
74.	Behrai	2.50	0.50	7.60	181.50	"	7.10	6.60	174.40	"	6.52	6.02	174.38	0.58	
75.	Namakpur	2.50	1.00	12.55	180.53	"	12.10	11.10	168.43	"	10.80	9.80	169.73	1.30	
76.	Kushalgarhi	1.60	0.40	7.85	180.40	"	7.72	7.32	172.68	"	7.58	7.18	172.82	0.14	
77.	Untasani	1.00	1.00	14.90	185.00	"	14.30	13.30	171.70	"	12.10	11.10	172.90	2.20	
78.	Mangarhi	2.00	1.25	19.98	183.25	"	19.77	18.52	163.48	"	17.22	15.97	166.03	2.55	
79.	Ramgarhi	1.80	0.95	15.25	182.95	"	14.20	13.25	168.75	"	12.17	11.22	170.78	2.03	
80.	Palkhera	2.15	0.15	9.60	187.15	"	9.35	9.20	177.80	"	7.86	7.71	173.29	1.49	
81.	Mirpur	1.50	0.75	8.60	181.75	13.6.92	8.40	7.65	173.35	13.11.92	7.32	6.57	174.43	1.08	22°C
82.	Mirpur Road	2.00	0.80	10.25	182.80	"	9.50	8.70	173.30	"	8.60	7.80	174.20	0.90	
83.	Haranpur	1.20	1.00	9.05	181.00	"	7.80	6.80	173.20	"	7.37	6.37	173.63	0.43	
84.	Hauli	1.25	1.00	7.40	185.00	"	5.85	4.85	179.15	"	4.50	3.50	180.50	1.35	
85.	Badipur	2.5	0.50	6.26	183.50	"	4.30	3.80	179.20	"	3.00	2.50	180.50	1.30	
86.	Pachara	2.10	1.00	5.00	185.00	"	2.40	1.40	182.60	"	1.78	0.78	183.22	0.62	
87.	Bhureka	0.85	1.50	6.45	189.50	"	3.25	1.75	186.25	"	2.78	1.28	186.72	0.47	
88.	Mohiuddinpur	2.00	1.00	4.20	184.50	"	2.70	1.70	181.80	"	1.94	0.94	182.56	0.76	
89.	Khaira	3.50	0.50	5.30	184.00	"	3.33	2.83	180.67	"	2.32	1.82	181.68	1.01	
90.	Tehra	1.72	0.70	6.65	193.00	"	4.30	3.60	178.70	"	3.05	2.35	179.95	1.25	23°C
91.	Kansera	1.75	0.50	12.60	189.50	14.6.92	12.20	11.70	177.30	14.11.92	10.69	10.19	178.81	1.51	
92.	Shahpur	2.20	1.65	12.65	196.65	"	13.20	12.55	183.45	"	10.99	10.34	185.66	2.21	
93.	Dule Khurd	1.90	0.46	12.35	195.46	"	12.70	12.24	182.76	"	10.74	10.28	184.72	1.96	

APPENDIX - IV

Hydrogeological data of Dugwells Inventoried in the Yamuna - Karwan Sub-basin in parts of Aligarh-Mathura Districts.
(June 1993 - November 1993)

Sl. No.	Location	Dia-meter (M)	Height of M.P. (AGL) (M)	Total Depth of the well (M)	R.L. of M.P. (M)	Pre-Monsoon				Post-Monsoon				water level fluc-tuation (m)	Temp.
						Date	Depth of water B.M.P. (M)	D.T.W. B.G.L. (M)	W.L. a.m.s.l. (M)	Date	D.T.W. B.M.P. (M)	D.T.W. B.G.L. (M)	W.L. a.m.s.l. (M)		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.	Khair	1.90	0.40	12.20	190.01	3.6.93	115.5	11.15	178.46	4.11.93	11.18	10.78	178.83	0.37	22°C
2.	Baloria	1.50	0.75	12.00	188.75	"	DRY	DRY	-	"	10.95	10.20	176.97	-	"
3.	Bhadera	2.75	0.60	13.00	187.60	"	DRY	DRY	-	"	12.92	12.32	174.68	-	"
4.	Palchand	3.40	1.00	11.30	191.00	"	10.98	9.98	180.02	"	9.95	8.95	181.05	1.03	"
5.	Nisuja	3.30	0.50	12.60	188.50	"	10.95	10.45	177.55	"	10.56	10.06	177.94	0.39	"
6.	Arni	2.50	1.50	12.20	193.50	"	11.15	9.65	182.35	"	10.20	8.70	183.30	0.95	"
7.	Nayabas	2.00	0.75	6.70	184.95	"	6.32	5.57	178.63	"	5.50	4.75	179.45	0.82	"
8.	Khairasattu	3.50	0.10	8.60	189.10	"	5.42	5.32	183.68	"	4.15	4.05	184.95	1.27	"
9.	Edalpur	2.40	0.65	5.80	190.65	"	5.23	4.58	185.42	"	3.35	2.70	187.30	1.88	"
10.	Mayarangarhi	2.70	1.00	4.45	188.00	"	2.15	1.15	185.85	"	1.85	0.85	186.15	0.30	"
11.	Sajnan	3.00	1.00	9.95	189.00	"	9.40	8.40	179.60	"	8.05	7.05	180.95	1.35	"
12.	Manpur	1.00	0.25	4.12	187.25	"	3.27	3.02	183.98	"	2.35	2.10	184.90	0.92	"
13.	Ahrola	2.00	2.00	6.35	193.00	"	4.80	2.80	188.20	"	4.15	2.15	188.85	0.65	"
14.	Shiwala Kalan	3.00	0.50	6.45	189.00	4.6.93	4.95	4.45	184.05	5.11.93	4.35	3.85	184.65	0.60	21°C
15.	Shiwala Khurd	3.00	0.50	8.50	188.50	"	3.72	3.22	184.78	"	3.52	3.02	184.98	0.20	
16.	Mathna	4.00	0.30	9.60	187.30	"	8.38	8.08	178.92	"	7.65	7.35	179.65	0.73	"
17.	Madannpur	2.50	1.50	7.00	185.50	"	5.85	4.35	179.65	"	4.82	3.32	180.68	1.03	
18.	Nagla	1.25	1.00	6.00	181.00	"	2.80	1.80	178.20	"	2.48	1.48	178.52	0.32	"
19.	Sujanpur	3.70	1.25	10.35	190.25	"	4.40	3.15	185.85	"	3.82	2.57	186.43	0.58	"
20.	Sujanpur-Khair Road	1.45	0.80	6.40	186.80	"	5.48	4.68	181.32	"	4.64	3.84	182.16	0.84	"
21.	Gomat	3.0	0.40	8.35	184.40	"	7.62	7.22	176.78	"	6.35	5.95	178.05	1.27	"
22.	Khera	3.0	1.0	9.50	190.0	"	6.10	5.10	183.90	"	5.20	4.20	184.80	0.90	"
23.	Narainpur	1.25	1.25	6.95	188.25	"	6.42	5.17	181.83	"	4.38	3.13	183.87	2.04	25°C
24.	Takipur	1.75	1.0	7.90	189.58	6.6.93	6.68	5.68	182.90	6.11.93	4.62	3.62	184.96	2.06	"
25.	Baluapur	2.50	0.70	8.90	187.70	"	6.78	6.08	180.92	"	4.90	4.20	182.80	1.88	"
26.	Karanpur	3.00	1.00	10.95	186.00	"	10.31	9.31	175.69	"	9.45	8.45	176.55	0.86	"
27.	Salpur	2.75	0.75	14.40	186.75	"	14.36	13.61	172.39	"	12.75	12.0	174.00	1.61	"
28.	Dajyadpur	3.00	1.25	14.60	187.25	"	14.53	13.28	172.72	"	12.65	11.40	174.60	1.88	"
29.	Nagolia	4.00	0.20	16.00	191.20	6.6.93	15.85	15.65	175.35	6.11.93	15.05	14.85	176.15	0.80	22°C
30.	Gatraula	2.00	1.50	17.00	196.50	"	DRY	DRY	-	"	16.30	14.80	180.20	-	"
31.	Ghagauli	2.00	1.00	20.80	191.00	"	20.72	19.72	170.28	"	20.04	19.04	170.96	0.68	"
32.	Simrauti	4.00	0.80	10.50	190.80	"	10.45	9.65	180.35	"	9.05	8.25	181.75	1.40	"
33.	Udaipur	2.00	1.20	13.70	185.20	7.6.93	13.62	12.42	171.58	7.6.93	11.45	10.25	173.75	2.17	"
34.	Tappal	4.5	2.50	10.90	198.76	"	10.65	8.15	188.11	"	7.65	5.15	191.11	3.0	"
35.	Nurpur	1.50	1.00	10.80	182.00	"	10.26	9.26	171.74	"	9.72	8.72	172.28	0.54	"
36.	Adampur	2.25	1.50	6.90	181.10	"	6.15	4.65	174.95	"	5.85	4.35	175.25	0.30	25°C
37.	Mahabalipur	1.50	1.00	8.30	183.60	"	7.69	6.69	175.91	"	7.27	6.27	176.33	0.42	"
38.	Gharbara	2.00	1.00	10.50	184.10	"	7.08	6.08	177.02	"	6.85	5.85	177.25	0.23	"
39.	Pipli	2.00	0.80	9.50	185.60	"	9.05	8.25	176.55	"	8.02	7.22	177.58	1.03	"
40.	Raipur	1.25	1.20	6.40	184.20	"	6.30	5.10	177.90	"	6.04	4.84	178.16	0.26	"
41.	Hamidpur	2.50	0.80	10.60	191.80	"	10.45	9.65	181.35	"	10.15	9.35	181.65	0.30	"
42.	Sarai	2.00	1.40	11.55	188.40	8.6.93	10.85	9.45	177.55	8.11.93	10.00	8.6	178.40	0.85	"
43.	Budhaka	2.00	0.50	7.70	194.50	"	5.63	5.13	188.87	"	5.05	4.55	189.45	0.58	"
44.	Attai	1.20	1.40	6.80	194.40	"	3.40	2.00	191.00	"	2.95	1.55	191.45	0.45	"
45.	Nagla Kurana	3.00	0.90	11.90	191.90	"	11.40	10.50	180.50	11.08	10.18	180.82	0.32	"	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
46.	Jattari	3.00	0.50	13.0	195.47	8.6.93	DRY	DRY	-	8.11.93	11.78	11.28	183.64	-	25°C
47.	Nagla Padam	2.25	1.20	15.95	193.20	"	15.80	14.60	177.40	"	14.62	13.22	178.58	1.18	"
48.	Sapha	0.80	0.40	7.40	188.65	"	5.96	5.56	182.69	"	5.42	5.02	183.23	0.54	"
49.	Rajpur	2.00	0.50	5.55	193.50	"	5.28	4.78	188.22	"	4.74	4.24	188.76	0.54	"
50.	Amargarhi	3.00	1.00	6.60	194.00	"	5.07	4.07	188.93	"	4.15	3.15	189.85	0.92	24°C
51.	Balulpur	3.00	1.50	9.80	191.50	"	5.72	4.22	185.78	"	5.12	3.62	186.38	0.60	"
52.	Nagla Bijna	3.00	1.00	9.40	193.00	9.6.93	5.83	4.83	187.17	10.11.93	5.32	4.32	187.68	0.51	"
53.	Shadipur	1.00	0.50	6.65	193.00	"	5.52	5.02	187.48	"	5.29	4.79	187.71	0.23	"
54.	Kara	2.50	1.25	5.90	193.25	"	5.48	4.23	187.77	"	5.08	3.83	188.17	0.40	"
55.	Mirpur Dhara	2.25	1.00	10.40	194.00	"	9.94	8.94	184.06	"	9.07	8.07	184.93	0.87	"
56.	Paspi	3.50	0.25	8.20	194.25	"	DRY	DRY	-	"	8.15	7.9	186.10	-	"
57.	Pisawan	1.75	0.40	14.70	196.19	"	DRY	DRY	-	"	11.32	10.92	184.87	-	22°C
58.	Mahijaura	3.00	0.90	17.00	196.90	"	16.94	16.04	179.96	2	16.05	15.15	180.85	0.89	"
59.	Sabalpur	1.75	1.10	14.55	196.10	"	14.40	13.30	181.70	"	13.87	12.77	182.23	0.53	"
60.	Chiti	3.00	0.30	14.65	195.30	"	14.52	14.22	180.78	"	13.77	13.47	181.53	0.75	"
61.	Alampur	3.50	0.70	13.55	194.70	"	12.92	12.22	181.78	"	10.87	10.17	193.83	2.05	"
62.	Jamunaka	4.00	0.50	12.10	190.50	"	12.04	11.54	178.46	"	10.54	10.04	179.96	1.5	"
63.	Rasulpur	1.45	1.10	9.70	193.10	11.6.93	8.10	7.0	185.00	11.11.93	6.92	5.82	186.18	1.18	"
64.	Jartauli	1.50	0.70	11.20	187.20	"	9.85	9.15	177.35	"	8.68	7.98	178.52	1.17	"
65.	Udaigarhi	2.50	1.00	9.00	184.70	"	5.85	4.85	178.85	"	5.08	4.08	179.62	0.77	"
66.	Edalgarhi	1.75	1.25	7.30	184.50	"	6.28	5.03	178.22	"	5.45	4.20	179.05	0.83	
67.	bajna	3.00	1.50	10.75	184.71	"	10.32	8.82	174.39	"	9.92	8.42	174.79	0.40	25°C
68.	Parsauli	3.00	1.60	12.30	184.00	"	9.22	7.62	174.78	"	8.16	6.56	175.84	1.06	"
69.	Baraut	2.00	1.00	12.25	182.52	"	11.44	10.44	171.08	"	11.05	10.05	171.47	0.39	"
70.	Bahlal	1.50	1.75	13.45	180.00	"	13.10	11.35	166.90	"	11.90	10.15	168.10	1.20	"
71.	Surir	3.50	1.00	15.50	182.71	"	11.18	10.18	171.53	2	9.65	8.65	173.06	1.53	"
72.	Nojhil	1.30	3.50	20.20	180.0	"	19.12	15.62	160.88	"	18.65	15.15	161.35	0.47	"
73.	Chinpari	1.30	1.00	7.70	179.50	"	7.04	6.04	172.46	"	6.48	5.48	173.02	0.56	23°C
74.	Behrai	2.50	0.50	7.60	181.50	12.6.93	7.29	6.79	174.21	12.11.93	6.70	6.20	174.80	0.59	"
75.	Namakpur	2.50	1.00	12.55	180.53	"	12.16	11.16	168.37	"	11.05	10.05	169.48	1.11	"
76.	Kushalgarhi	1.60	0.40	7.85	180.40	"	7.78	7.38	172.62	"	7.58	7.18	172.82	0.20	"
77.	Untasani	1.00	1.00	14.90	185.00	"	14.30	13.30	170.70	"	12.70	11.70	172.30	1.60	"
78.	Mangarhi	2.00	1.25	19.98	183.25	"	19.95	18.70	163.30	"	18.20	16.95	165.05	1.75	"
79.	Ramgarhi	1.80	0.95	15.25	182.95	"	14.53	13.58	168.42	"	13.67	12.72	169.28	0.86	"
80.	Palkhera	2.15	0.15	9.60	187.15	"	8.33	8.18	178.82	"	8.05	7.90	179.10	0.28	22°C
81.	Mirpur	1.50	0.75	8.60	181.75	"	8.44	7.69	173.31	"	7.65	6.90	174.10	0.79	"
82.	Mirpur Road	2.00	0.80	10.25	182.80	"	9.61	8.88	173.19	"	9.20	8.29	173.78	0.59	"
83.	Haranpur	1.20	1.00	9.05	181.00	"	8.40	7.40	172.60	"	8.07	7.07	172.93	0.33	"
84.	Naoli	1.25	1.00	7.40	185.00	13.6.93	6.08	5.08	178.92	13.11.93	5.72	4.72	179.28	0.36	"
85.	Badlipur	2.5	0.50	6.26	183.50	"	4.25	3.75	179.25	"	3.23	2.73	180.27	1.02	"
86.	Pachara	2.10	1.00	5.00	185.00	"	2.22	1.22	182.78	"	1.74	0.74	183.26	0.48	"
87.	Bhureka	0.85	1.50	6.45	189.50	"	3.14	1.64	186.36	"	2.98	1.48	186.52	0.16	"
88.	Moinuddinpur	2.00	1.00	4.20	184.50	"	2.44	1.44	182.06	"	2.05	1.05	182.45	0.41	"
89.	Khaira	3.50	0.50	5.30	184.00	"	3.27	2.77	180.73	"	2.52	2.02	181.48	0.75	"
90.	Tehra	1.72	0.70	6.65	193.00	14.6.93	4.16	3.46	178.84	"	3.45	2.75	179.55	0.71	23°C
91.	Kansera	1.75	0.50	12.60	189.50	"	12.48	11.98	177.02	"	11.08	10.58	178.42	1.40	"
92.	Shahpur	2.20	1.65	12.65	196.65	"	DRY	DRY	-	"	11.50	10.85	185.15	-	"
93.	Dule Khurd	1.90	0.46	12.35	195.46	"	DRY	DRY	-	"	11.06	10.60	184.40	-	"

APPENDIX - V

Results of mechanical analysis of aquifer material

Location: Tappal

Depth: 130'

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.21	0.21	0.21	99.79
35	0.50	0.19	0.19	0.40	99.60
45	0.35	0.52	0.52	0.92	99.08
60	0.25	3.15	3.18	4.10	95.90
80	0.17	4.51	4.55	8.65	91.35
120	0.12	37.19	37.55	46.2	53.30
170	0.08	29.77	30.05	75.25	23.75
230	0.06	18.32	18.49	94.74	5.26
Pan	0.06	5.03	5.07	99.81	0.19

Location: Jamunka

Depth: 70'

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.80	0.08	0.80	99.92
35	0.50	0.48	0.48	0.56	99.44
45	0.35	2.50	2.53	3.09	96.61
60	0.25	31.65	32.14	35.23	64.77
80	0.17	23.53	23.89	59.12	40.88
120	0.12	32.93	33.44	92.56	7.44
170	0.08	4.15	4.21	96.77	3.29
230	0.06	1.62	1.64	98.41	1.59
Pan	0.06	0.81	0.82	99.23	0.77

Location: Musmana

Depth: 70'

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.19	0.09	0.09	99.91
35	0.50	0.22	0.11	0.20	99.98
45	0.35	1.88	0.95	1.15	98.85
60	0.25	43.39	21.89	23.04	76.96
80	0.17	37.92	19.13	42.17	57.83
120	0.12	91.32	46.09	99.25	11.57
170	0.08	15.59	7.87	96.12	3.88
230	0.06	5.77	2.91	99.03	0.97
Pan	0.06	1.83	0.92	99.95	0.00

Location: Palsera

Depth: 90'

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	2.68	2.69	2.69	97.31
35	0.50	0.18	0.18	2.87	97.13
45	0.35	0.29	0.29	3.18	96.84
60	0.25	3.05	3.06	6.22	93.78
80	0.17	6.12	6.15	12.37	87.63
120	0.12	41.96	42.22	54.59	45.41
170	0.08	24.39	24.54	79.13	20.87
230	0.06	15.15	15.24	94.37	5.63
Pan	0.06	5.55	5.85	100.24	0.00

Location: Nojhil

Depth: 113'

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	6.09	3.08	3.08	96.92
35	0.50	4.28	2.17	5.25	94.75
45	0.35	23.11	11.70	16.95	83.05
60	0.25	109.37	55.41	72.36	27.64
80	0.17	17.32	8.77	81.13	18.87
120	0.12	29.45	14.92	96.05	3.95
170	0.08	3.22	1.63	97.68	2.32
230	0.06	3.22	1.63	99.31	0.69
Pan	0.06	1.29	0.06	99.96	0.04

APPENDIX - VI-A

Results of mechanical analysis of the Yamuna sand

Mesh No.	Size in (mm)	Weight retained	Weight % retained in gram	Cumulative weight % trained	Cumulative weight % passing
Location: Chinpari (Yamuna River) Depth: 30 cms					
20	0.84	-	-	-	100.00
25	0.71	0.02	0.02	0.02	99.98
35	0.50	0.10	0.10	0.12	99.88
45	0.35	0.69	0.70	0.82	99.18
60	0.25	13.09	13.30	14.12	85.88
80	0.17	23.14	23.51	37.63	62.37
120	0.12	51.46	52.46	90.09	9.91
170	0.08	7.42	7.53	97.62	2.38
230	0.06	1.87	1.90	99.52	0.48
Pan	0.06	0.44	0.44	99.96	0.04

Location: Chinpari (Yamuna river)

Depth: 100 cm

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.03	0.03	0.03	99.97
35	0.50	0.06	0.06	0.09	99.91
45	0.35	0.26	0.26	0.35	99.65
60	0.25	2.68	2.71	3.06	96.94
80	0.17	7.42	7.50	10.56	89.44
120	0.12	58.67	59.34	69.90	30.10
170	0.08	21.37	21.61	91.51	8.49
230	0.06	6.60	6.60	98.10	1.89
Pan	0.06	1.77	1.79	99.90	0.00

Location: Untasani (Yamuna river)

Depth: 30 cms

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.02	0.02	0.02	99.98
35	0.50	0.06	0.06	0.08	99.92
45	0.35	0.50	0.50	0.13	99.87
60	0.25	8.98	9.08	9.21	90.79
80	0.17	18.39	18.60	27.81	72.19
120	0.12	52.90	53.49	81.30	18.70
170	0.08	10.07	10.18	91.48	8.52
230	0.06	4.87	4.92	96.40	3.62
Pan	0.06	3.09	3.12	99.52	0.48

Location: Untasani (Yamuna river)

Depth: 100 cms

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.01	0.01	0.01	99.99
35	0.50	0.06	0.06	0.07	99.93
45	0.35	0.35	0.35	0.42	99.58
60	0.25	3.85	3.89	4.31	95.69
80	0.17	16.93	17.11	21.42	78.58
120	0.12	53.10	53.69	75.10	24.89
170	0.08	17.98	18.17	93.28	6.72
230	0.06	3.57	3.60	96.88	3.12
Pan	0.06	3.05	3.08	99.96	0.04

APPENDIX - VI-B

Results of mechanical analysis of Karwan river sand

Location: Khair (Karwan river)

Depth: 30 cms

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.04	0.04	0.04	99.96
35	0.50	0.16	0.17	0.21	99.79
45	0.35	0.55	0.56	0.77	99.23
60	0.25	4.22	4.26	5.03	94.97
80	0.17	7.68	7.75	12.78	87.22
120	0.12	57.82	58.38	71.16	28.84
170	0.08	19.42	19.61	90.77	9.23
230	0.06	6.69	6.75	97.52	2.48
Pan	0.06	2.19	2.21	99.73	0.00

Location: Khair (Karwan river)

Depth: 100 cms

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.01	0.01	0.01	99.90
35	0.50	0.09	0.09	0.11	99.58
45	0.35	0.32	0.32	0.53	93.14
60	0.25	6.34	6.44	6.97	74.25
80	0.17	18.58	18.89	25.86	16.57
120	0.12	56.72	57.68	93.54	5.44
170	0.08	10.95	11.13	94.67	1.94
230	0.06	3.44	3.50	98.17	1.94
Pan	0.06	1.87	1.90	-	0.00

Location: Alampur (Karwan river)

Depth: 30 cms

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.41	0.04	0.04	99.96
35	0.50	0.17	0.17	0.21	99.79
45	0.35	0.67	0.67	0.88	99.12
60	0.25	3.82	3.83	4.71	95.29
80	0.17	5.72	5.74	10.45	89.55
120	0.12	46.32	46.54	56.99	43.01
170	0.08	26.19	26.31	83.30	16.70
230	0.06	11.43	11.48	94.79	5.22
Pan	0.06	5.15	5.17	99.96	0.00

Location: Alampur (Karwan river)

Depth: 100 cms

Mesh No.	Size in (mm)	Weight retained in gram	Weight % retained	Cumulative weight % retained	Cumulative weight % passing
20	0.84	-	-	-	100.00
25	0.71	0.30	,0.30	,0.30	99.70
35	0.50	1.84	1.84	2.14	97.86
45	0.35	4.58	4.62	6.76	93.24
60	0.25	7.13	7.20	13.96	86.04
80	0.17	5.59	5.60	19.60	80.40
120	0.12	40.69	41.07	60.67	39.33
170	0.08	20.31	20.73	81.40	18.60
230	0.06	11.75	11.86	93.26	6.74
Pan	0.06	6.88	6.94	100.00	0.00

APPENDIX - VII

Showing the values of Transmisivity (T), Permeability (K) and Specific Capacity Index, Calculated as per Logan's (1964) formula

S.No.	Location	Thickness of aquifer tapped (m)	Discharge (m^3/day)	Drawdown (m)	Specific capacity (m^2/day)	Transmissivity (m^2/day)	Permeability (m/day)	Yield factor (m/day)
1.	Nagla	26.0	3005.60	3.65	823.60	1004.61	38.63	31.67
2.	Gomat	30.0	3130.32	3.65	857.62	1046.29	34.89	28.58
3.	Resri	21.0	3034.80	5.5	551.78	673.17	32.05	26.27
4.	Amargarhi	25.6	2942.4	5.25	560.45	683.75	26.70	21.89
5.	Chiti	34.45	3975.60	5.5	722.83	881.86	25.59	21.00
6.	Jamunka	18.59	2086.56	5.5	379.37	462.83	24.89	20.4
7.	Nagla Bijna	40.8	4968.0	6.09	828.00	1010.16	27.75	20.30
8.	Shahpur	30.0	3975.6	5.5	722.80	881.86	29.40	24.09
9.	Bazidpur	40.5	3965.28	4.0	991.32	1209.41	29.86	24.47
10.	Rasulpur	34.43	5949.5	7.0	849.92	1036.90	30.11	24.68
11.	Hamidpur	30.5	4250.88	6.7	634.45	774.04	25.37	20.80
12.	Jahangarhi	21.3	3880.80	7.2	530.66	647.4	30.35	24.90
13.	Jalgarhi	34.43	5949.50	7.0	849.92	1036.9	30.11	24.68
14.	Musmana	29.4	4847.04	7.01	692.43	844.76	28.73	23.55
15.	Daulatpur	37.0	4924.4	7.0	703.5	858.32	23.19	19.01
16.	Nojhil	15.77	2192.4	5.3	413.7	504.7	31.5	26.18
17.	Adda	25.30	3542.4	6.5	544.98	664.88	26.27	21.54
18.	Jarara	28.64	2592.0	4.9	528.97	645.35	22.53	18.5
19.	Surir	20.0	3228.0	7.5	425.01	523.78	26.18	21.25
20.	Bholol	25.30	3542.4	6.5	544.98	664.88	26.27	21.54
21.	Naoli	30.30	4809.02	5.0	956.00	1173.40	38.72	31.55

APPENDIX - VIII(A)

Pumping Test Data of and Observations during
Pumping of Sopha well

Time since Pump started "t" (in minutes)	Main Well		Observation Well	
	Water level (m.b.m.p.)	Draw down (m)	Water level (m.b.m.p.)	Draw down (m)
1	2	3	4	5
0	7.08	-	7.33	-
1	10.13	3.05	8.88	1.55
2	10.67	3.59	9.17	1.84
3	10.72	3.64	9.35	2.02
4	10.91	3.83	9.48	2.15
5	10.96	3.88	9.58	2.25
6	11.02	3.94	9.69	2.36
7	11.12	4.04	9.75	2.42
8	11.14	4.06	9.81	2.48
9	11.25	4.17	9.86	2.53
10	11.39	4.31	9.92	2.59
11	11.48	4.40	9.97	2.64
12	11.45	4.37	10.02	2.69
13	11.57	4.49	10.05	2.72
14	11.49	4.41	10.09	2.76
15	11.51	4.43	10.12	2.79
16	11.50	4.42	10.15	2.82
17	11.63	4.55	10.17	2.84
18	11.76	4.68	10.20	2.87
19	11.69	4.61	10.24	2.81
20	11.69	4.61	10.27	2.94
21	11.78	4.70	10.29	2.96
22	11.75	4.67	10.32	2.99
23	-	-	10.34	3.01
24	-	-	10.36	3.03
25	11.75	4.67	10.38	3.05
26	11.91	4.83	10.39	3.06
27	11.73	4.65	10.41	3.08

1	2	3	4	5
28	11.87	4.79	10.42	3.09
29	11.91	4.83	10.44	3.11
30	11.89	4.81	10.46	3.13
32	11.93	4.85	10.49	3.16
34	12.03	4.95	10.53	3.20
36	11.90	4.90	10.56	3.23
38	12.06	4.98	10.58	3.25
40	12.05	4.97	10.61	3.28
42	12.07	4.99	10.63	3.30
44	12.07	4.99	10.65	3.32
46	12.06	4.98	10.68	3.35
48	12.15	5.07	10.69	3.36
50	12.12	5.04	10.71	3.38
52	12.16	5.00	10.72	3.39
54	12.15	5.07	10.75	3.42
56	12.32	5.24	10.77	3.44
58	12.16	5.08	10.70	3.45
60	12.18	5.10	10.80	3.47
65	12.35	5.27	10.83	3.50
70	12.18	5.10	10.87	3.54
75	12.20	5.12	10.91	3.50
80	12.34	5.26	10.94	3.61
85	12.32	5.28	10.97	3.64
90	12.33	5.25	10.99	3.66
95	12.41	5.33	11.02	3.60
100	12.42	5.34	11.04	3.71
105	12.50	5.42	11.07	3.74
110	12.42	5.34	11.08	3.75
115	12.52	5.44	11.10	3.77
120	12.52	5.44	11.12	3.79
130	12.53	5.45	11.16	3.83
140	12.55	5.47	11.19	3.86
150	12.53	5.45	11.22	3.89
160	12.55	5.47	11.25	3.92
170	12.62	5.54	11.28	3.95
180	12.60	5.52	11.30	3.97

1	2	3	4	5
195	12.80	5.72	11.32	3.99
210	12.68	5.60	11.37	4.04
225	12.79	5.71	11.38	4.05
240	12.79	5.71	11.40	4.07
270	12.82	5.74	11.48	4.15
300	12.88	5.80	11.51	4.18
330	12.94	5.86	11.55	4.22
360	12.94	5.86	11.59	4.26
420	13.02	5.94	11.64	4.31
400	13.01	5.93	11.68	4.35
540	13.11	6.03	11.73	4.40
660	13.23	6.15	11.79	4.46
780	13.24	6.16	11.84	4.51
900	13.31	6.28	11.87	4.54
1020	13.32	6.24	11.92	4.59
1140	13.23	6.15	11.94	4.61
1260	13.33	6.25	11.96	4.63
1380	13.24	6.16	11.98	4.65
1440	-	-	11.98	4.65
1465	13.38	6.30	11.98	4.65

Pumping stopped after 1465 minutes.

APPENDIX - VIII(B)

Recovery Test Data of Pumping Test at Village Sopha
Pump shutdown at 1465 minutes

Time since pump started in minutes (t)	Time since pump stopped in minutes (t')	t/t'	Residual drawdown in metres	
			Main well	Obs. well
1	2	3	4	5
1466	1	1466	3.17	3.21
1467	2	734	2.75	2.86
1468	3	489	-	2.65
1469	4	367	2.66	2.50
1470	5	294	2.42	2.39
1471	6	245	2.35	2.29
1472	7	210	2.30	2.21
1473	8	184	2.20	2.14
1474	9	164	2.12	2.08
1975	10	148	2.10	2.02
1476	11	134	2.06	1.97
1477	12	123	2.03	1.93
1478	13	114	1.97	1.89
1479	14	106	1.97	1.85
1480	15	99	1.98	1.81
1481	16	93	1.09	1.79
1482	17	87	1.82	1.75
1483	18	82	1.82	1.72
1484	19	78	1.73	1.70
1485	20	74	1.74	1.67
1486	21	71	1.73	1.65
1487	22	68	1.70	1.62
1488	23	65	1.62	1.59
1489	24	62	1.73	1.57
1490	25	60	1.63	1.55
1491	26	57	1.68	1.54
1492	27	55	1.66	1.51
1493	28	53	1.54	1.50
1494	29	52	1.57	1.49

1	2	3	4	5
1495	30	50	1.57	1.49
1497	32	47	1.57	1.44
1499	34	44	1.48	1.40
1501	36	42	1.44	1.37
1503	38	40	1.53	1.34
1505	40	38	1.47	1.31
1507	42	36	1.46	1.28
1509	44	34	1.38	1.27
1511	46	33	1.41	1.25
1513	48	31	1.25	1.22
1515	50	30	1.29	1.20
1517	52	29	1.30	1.18
1519	54	28	1.22	1.17
1521	56	27	1.27	1.15
1523	58	26	1.17	1.13
1525	60	25	1.18	1.12
1530	65	24	0.97	1.08
1535	70	22	1.13	1.05
1540	75	21	1.00	1.01
1545	80	19	0.84	0.99
1550	85	18	0.98	0.96
1555	90	17	0.98	0.92
1565	100	16	0.82	0.89
1575	110	14	0.89	0.84
1585	120	13	0.71	0.78
1595	130	12	0.72	0.73
1605	140	11	0.88	0.70
1615	150	11	0.74	0.68
1630	165	10	0.74	0.63
1645	180	9	0.77	0.60
1660	195	9	0.72	0.57
1675	210	8	0.61	0.54

1	2	3	4	5
1705	240	7	0.55	0.49
1735	270	6	0.64	0.45
1765	300	6	0.37	0.43
1795	330	5	0.44	0.39
1825	360	5	0.40	0.37
1855	390	5	0.36	0.33
1885	420	4	0.34	0.31

APPENDIX - IX-A

Results of partial chemical analysis of water samples collected from observation wells during June, 1992

(Results in ppm)

S.No.	Location	pH	E.C. micro-mhos/cm at 25°C	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	Na^+	K^+	Ca^{++}	Mg^{++}	F^-	T.D.S.	Total Hardness	Temp. °C
1.	Khair	7.71	985	8	175	100	65	70	37	46	28	0.07	430	150	22
2.	Sujanpur	7.80	673	9	256	114	120	44.5	6.5	20	25	0.09	250	400	22
3.	Sopha	8.73	885	10	270	303	69.95	58.8	20	30	54	0.06	575	445	21
4.	Rajpur	7.42	1011	12	256	213	65	90	28	31	20	0.07	373	515	22
5.	Amangarhi	8.10	1000	16	158	403	96	44	61	48	30	0.04	260	600	21
6.	Shadipur	7.51	1234	16	550	100	54	122	15	28	27	0.03	813	575	22
7.	Bhadera	7.90	1120	18	648	206	58	150	33	35	54	0.20	753	618	22
8.	Kasion	7.50	1011	40	842	73	127	144.4	76	48	35	1.30	315	700	23
9.	Gomat	8.21	667	15	329	57	75	90	61	12	28	1.10	251	155	22
10.	Dewa Hamidpur	7.90	895	12	595	52	80	180	12	14	25	0.56	500	230	22
11.	Jumunka	8.03	2558	46	781	262	150	195	460	52	71	0.33	430	420	22
12.	Padamnagla	9.06	458	9	244	46	94	22	55	64	27.4	0.44	313	170	22
13.	Chiti	8.89	584	15	335	52	210	44	44	51	44	0.49	250	175	20
14.	Dalehurd	8.70	995	7	159	53.2	150	48	36	55	56	0.07	268	180	23
15.	Pisawan	9.02	1204	28	365	54.2	110	58	14	58	50	0.08	245	230	21
16.	Edalpur	7.81	2113	25	329	277	410	350	28	56	156	0.07	340	325	21
17	Nisuja	7.70	2157	10	158	183	104	138	95	51	116	0.09	273	475	21
18.	khera	8.13	1458	34	473	203	66	113	133	53	102	1.23	260	515	22
19.	Shiwala Khurd	8.21	2558	9	354	255	100	390	184	8	33	1.01	252	155	22
20.	Nayabas	8.80	778	12	448	413	94	158	120	44	141	1.10	340	545	22
21.	Bajna	7.79	1020	13	603	156	51	148	73	65	140	1.02	444	498	22
22.	Jattari	8.90	3066	45	677	436	680	713	20	16	47	0.09	513	675	22
23.	Tappal	8.21	1200	9	230	95	146	78	33.8	61	30	1.30	470	300	21
24	Hamidpur	8.01	1170	12	408	60	55	208	9.5	65	25	1.23	380	350	22
25.	Rasulpur	7.71	1000	14	393	65	33	63	4.8	78	27	1.45	340	415	22
26.	Maharajpur	7.80	2017	17	708	68	48	54	6.8	55	28	1.69	515	515	22
27.	Untasani	8.11	875	11	159	73	55	66	11	41	23	0.48	449	608	22
28.	Salpur	7.70	7200	18	415	1106	72	800	260	94	160	0.49	954	485	23
29.	Kilpur	7.90	475	24	248	160	60	48	28	40	160	0.38	1132	858	23
30.	Karanpur	8.91	973	27	480	315	59	200	27	68	101	0.56	1440	753	21
31.	Takipur	8.91	743	33	408	89	95	170	6.1	16	16	1.45	513	170	21
32.	Shahpur	7.90	300	12	475	53	114	113.50	3.5	21	24	1.02	640	185	21
33.	Palsera	7.70	1145	23	415	99	55	168	9.5	10	38	1.16	273	180	22
34.	Helalpur	7.40	895	13	295	48	43	105	11	23	44	0.16	464	240	22
35.	Simarauti	7.51	1511	8	24	881	102	195	44	21	68	0.84	253	230	22
36.	Nurpur	7.41	1375	13	55	667	112	180	48	22	22	0.12	441	403	22
37.	Attai	7.80	973	14	95	230	64	183	93	38	32	0.89	253	250	22
38.	Bhagwangarhi	8.35	934	18	342	64	55	87	5.2	72	38	1.34	848	340	22
39.	Milhali	8.12	2980	36	549	540	44	500	10	52	84	1.60	2150	480	21
40.	Mangarhi	8.55	1353	30	439	135	87	200	4.5	20	38	1.50	1500	210	22
41.	Kulana	8.33	1926	12	439	312	110	220	10	64	79	0.90	1440	490	20
42.	Adda	8.53	1465	30	290	281	119	160	15	76	48	1.10	953	390	20
43.	Bhairai	8.44	1646	11	122	213	213	160	12	64	72	0.06	350	260	22
44.	Nojhil	8.85	1024	10	180	45	164	100	26	45	25	0.40	200	180	22
45.	Sultanpur	8.42	3760	24	305	670	144	450	9.5	125	118	0.35	413	880	22
46.	Surir	8.11	5080	36	488	610	105	798	14	88	31	1.20	343	350	22
47.	Nabtauli	8.57	2450	24	415	130	55	200	400	44	41	1.20	500	280	22
48.	Pachara	8.16	2112	20	476	113	99	213	120	45	145	1.30	320	958	22

Contd....2

Contd......

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
49.	Ramnagla	8.33	2630	36	549	419	111	150	500	68	160	1.50	315	1020	22
50.	Chinpari	8.17	1413	30	522	213	213	141	30	23	115	1.48	308	615	21
51.	Parsauli	8.27	1412	31	603	99	208	144	14	38	103	1.39	450	768	21
52.	Baraut	7.94	1213	24	525	802	217	690	12	116	84	1.20	470	640	23
53.	Vijaigarhi	8.62	1024	15	203	809	303	135	24	20	40	0.48	390	600	23
54.	Jarara	9.06	1670	46	805	106	223	250	4.0	21	67	1.89	545	330	23
55.	Haranpur	8.10	1372	35	615	112	228	165	26	28	60	0.12	440	340	20
56.	Muwaka	7.97	1739	25	523	156	195	60	21	52	46	0.64	600	320	20
57.	Naoli	8.27	1207	33	773	51	190	95	2.5	41	44	1.26	615	1018	22
58.	Musandgarhi	8.62	2610	46	842	57	144	400	21	28	48	1.81	498	250	22
59.	Dajyadpur	7.64	1030	18	295	52	604	313	44	44	33	0.48	506	153	22
60.	Sajnan	7.5	916	12	167	45	218	65	33	45	25	0.04	350	185	22

APPENDIX - IX-B

Concentration of major ions in water samples of observation wells during June, 1992

(Results in epm)

S.No.	Location	pH	E.C.	Co_3^{--}	HCo_3^-	Cl^-	So_4^{--}	Na^+	K^+	Ca^{++}	Mg^{++}	Na %	S.A.R.*	Salinity	R.C.**
1.	Khair	7.71	985	0.26	2.84	2.82	7.35	3.04	0.94	2.89	2.30	45.44	2.0	C_3S_1	0.16
2.	Sujanpur	7.80	673	0.30	4.19	3.21	2.50	1.93	0.16	0.99	2.05	40.75	1.56	C_2S_1	1.45
3.	Sopha	8.73	885	0.33	4.42	8.54	1.45	2.55	0.51	1.49	4.44	34.03	1.48	C_3S_1	-
4.	Rajpur	7.42	1011	0.4	2.55	6.00	1.35	3.91	0.71	1.54	1.64	59.23	3.10	C_3S_1	-
5.	Amangarhi	8.10	1000	0.53	2.58	11.36	1.99	1.91	1.56	2.39	2.46	41.76	1.23	C_3S_1	-
6.	Shadipur	7.51	1234	0.53	9.01	2.82	1.12	5.30	0.38	1.39	2.22	61.14	3.95	C_3S_1	5.93
7.	Bhadera	7.90	1120	0.6	10.67	5.80	1.20	6.52	0.84	1.74	4.44	54.35	3.72	C_3S_1	
8.	Kasion	7.50	1011	1.33	13.80	2.05	2.64	6.27	1.94	1.54	2.87	65.05	4.23	C_3S_1	1072
9.	Gomat	8.21	667	0.5	5.39	1.60	1.56	3.91	1.56	0.59	2.30	65.43	0.25	C_2S_1	3.0
10.	Dewa Hamidpur	7.90	895	0.4	9.75	1.46	1.66	7.82	0.30	0.69	2.05	74.76	6.68	C_3S_1	7.41
11.	Jumunka	8.03	2558	1.53	12.80	7.38	3.12	8.47	11.76	2.59	5.83	70.61	4.13	C_4S_1	5.91
12.	Padamnagla	9.06	458	0.30	3.99	1.29	1.95	0.95	1.40	3.19	2.25	30.16	0.57	C_2S_1	-
13.	Chiti	8.89	584	0.5	5.49	1.46	4.37	1.91	1.12	2.54	3.61	33.00	0.98	C_2S_1	-
14.	Dalehurd	8.70	995	0.23	2.60	1.50	3.12	2.08	0.39	2.74	4.60	25.17	1.11	C_3S_1	-
15.	Pisawan	9.02	1204	0.93	5.68	1.12	2.29	2.52	0.35	2.89	4.11	29.07	0.90	C_3S_1	5.26
16.	Edalpur	7.81	2113	0.83	5.39	7.81	8.53	15.21	0.76	2.79	12.82	50.56	5.45	C_3S_1	-
17	Nisuja	7.70	2157	0.33	2.58	5.16	2.16	6.0	2.42	2.54	9.53	41.09	2.44	C_3S_1	-
18.	khera	8.13	1458	1.13	7.75	5.72	1.37	4.91	3.40	2.64	8.38	42.99	2.09	C_3S_1	-
19.	Shiwala Khurd	8.21	2558	0.30	5.80	7.19	2.08	16.95	4.70	0.39	2.71	87.47	13.66	C_4S_3	3.0
20.	Nayabas	8.80	778	0.4	7.34	11.64	1.95	6.86	3.06	2.19	11.59	41.85	2.61	C_3S_1	-
21.	Bajna	7.79	1020	0.43	9.88	4.39	1.06	6.43	1.86	3.24	11.51	35.89	2.37	C_3S_1	-
22.	Jattari	8.90	3066	1.5	11.09	12.29	14.15	31.0	0.51	0.79	3.86	87.14	20.39	C_4S_3	7.94
23.	Tappal	8.21	1200	0.3C	3.76	2.67	3.03	3.39	0.86	3.04	2.46	43.58	2.05	C_3S_1	-
24	Hamidpur	8.01	778	0.4	10.68	1.69	1.14	9.04	0.24	3.24	2.05	63.69	5.58	C_3S_1	1.79
25.	Rasulpur	7.71	1000	0.46	6.44	1.83	0.68	2.73	0.12	3.89	2.22	31.80	1.56	C_3S_1	0.79
26.	Maharajpur	7.80	2014	0.56	11.60	1.91	0.99	2.34	0.17	2.74	2.30	33.42	1.48	C_3S_1	7.12
27.	Untasani	8.11	875	0.36	2.60	2.05	1.72	2.86	0.28	2.04	1.89	44.41	2.04	C_3S_1	-
28.	Salpur	7.70	7200	0.6	6.80	31.19	1.49	34.78	6.64	4.69	13.15	84.08	17.65	C_4S_2	-
29.	Kilpur	7.90	475	0.8	4.06	4.15	1.24	2.08	0.76	1.99	13.15	15.79	0.36	C_2S_1	-
30.	Karanpur	8.91	973	0.9	8.03	8.88	1.22	8.69	0.69	3.39	8.30	44.51	3.60	C_3S_1	-
31.	Takipur	8.91	743	1.1	6.68	2.50	1.97	7.39	0.15	0.79	1.31	70.21	7.24	C_2S_1	5.68
32.	Shahpur	7.90	300	0.4	7.78	1.49	2.37	4.93	0.08	1.04	1.97	62.46	4.04	C_2S_1	5.17
33.	Palsera	7.70	1145	0.76	6.80	2.79	1.14	7.30	0.24	0.49	3.12	67.62	5.44	C_3S_1	3.95
34.	Helalpur	7.40	895	0.43	4.83	1.35	0.89	4.56	0.28	1.14	3.61	50.46	2.96	C_3S_1	0.51
35.	Simarauti	7.51	1511	0.26	0.39	24.8	2.12	8.47	1.12	1.04	5.59	59.12	4.65	C_3S_1	-
36.	Nurpur	7.41	1375	0.43	0.90	18.80	2.33	7.82	1.22	1.09	1.80	75.77	6.51	C_3S_1	-
37.	Attai	7.80	973	0.46	1.55	6.48	1.33	7.95	2.37	1.89	2.63	69.54	5.30	C_3S_1	-
38.	Bhagwangarhi	8.35	934	0.53	6.60	1.80	1.14	3.78	0.13	3.59	3.12	36.81	2.06	C_3S_1	
39.	Milhali	8.12	2980	1.2	8.99	15.22	0.91	21.73	0.25	2.59	6.90	69.84	10.01	C_4S_2	0.7
40.	Mangarhi	8.55	1353	1.0	7.19	3.80	1.81	8.69	0.11	0.99	3.12	68.16	6.07	C_3S_1	-
41.	Kulana	8.33	1926	0.4	7.19	8.79	2.29	9.56	0.25	3.19	6.49	50.33	4.34	C_3S_1	-
42.	Adda	8.53	1465	1.0	3.01	7.72	2.47	6.95	0.38	3.79	3.94	48.67	3.52	C_3S21	-
43.	Bhairai	8.44	1646	0.36	1.99	6.00	4.43	6.95	0.30	3.19	5.92	44.31	3.26	C_3S_1	-
44.	Nojhil	8.85	1024	0.33	3.95	1.26	3.41	4.34	0.66	2.24	2.05	53.82	2.97	C_3S_1	-
45.	Sultanpur	8.42	3760	0.80	4.99	18.89	2.99	19.56	0.24	6.23	9.70	55.41	6.93	C_4S_1	-
46.	Surir	8.11	5080	1.2	7.99	16.68	2.18	34.69	0.35	4.39	2.54	83.48	18.65	C_4S_2	2.26
47.	Nabtauli	8.57	2450	0.8	6.80	3.66	1.14	8.69	10.23	2.19	3.37	77.28	5.23	C_4S_1	2.04
48.	Pachara	8.16	2112	0.66	7.80	3.18	2.06	9.26	3.06	2.24	11.92	46.52	3.48	C_3S_1	-

Contd...

Contd....

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
49.	Ramnagla	8.33	2630	1.2	8.99	11.61	2.31	6.52	12.78	3.39	13.15	53.83	2.27	C_4S_1	-
50.	Chinpari	8.17	1413	1.0	8.55	6.00	4.43	6.13	0.76	1.14	9.45	39.41	2.66	C_3S_1	
51,	Parsauli	8.27	1412	1.03	9.88	2.79	4.33	6.26	0.35	1.89	8.47	38.95	2.75	C_3S_1	0.55
52.	Baraut	7.94	1213	0.8	6.60	22.61	4.51	30.0	0.30	5.78	6.90	70.49	11.95	C_3S_2	-
53.	Vijaigarhi	8.62	1410	0.5	3.32	22.81	6.30	5.86	0.61	0.99	3.28	7.24	4.01	C_3S_1	
54.	Jarara	9.06	1670	1.53	13.19	2.98	4.64	10.86	0.10	1.04	5.50	62.62	6.03	C_3S_1	8.18
55.	Haranpur	8.10	1372	1.16	10.08	3.15	4.74	7.17	0.66	1.39	4.93	55.33	4.05	C_3S_1	4.92
56	Muwaka	7.97	1739	0.83	8.57	4.39	8.05	2.60	0.53	2.59	3.78	32.94	1.46	C_3S_1	3.03
57.	Naoli	8.27	1207	1.1	12.67	1.43	3.95	4.13	0.06	2.04	3.61	42.58	2.45	C_3S_1	8.12
58.	Musandgarhi	8.62	2610	1.53	13.80	1.60	2.99	17.39	0.66	1.39	3.94	77.20	10.35	C_4S_2	9.00
59.	Dajyadpur	7.46	1030	0.53	4.83	1.46	12.57	13.60	1.12	2.19	2.71	76.64	8.71	C_3S_1	0.46
60.	Sajran	7.5	916	0.4	2.73	1.26	4.53	2.82	0.84	2.24	2.05	46.03	1.93	C_3S_1	-

S.A.R* = Sodium adsorption ratio

R.C** = Residual carbonate

APPENDIX - X-A

Trace element data of the water samplescollected from dug well.

(Results in ppm)

S.No.	Location	Fe	Cu	Zn	Mn	Pb	Cd	Cr	Sr
1.	Khair	0.301	0.051	2.941	0.126	0.390	0.031	0.0431	1.260
2.	Sopha	0.231	0.041	1.861	0.141	0.101	0.011	0.0298	1.20
3.	Sujanpur	0.101	0.027	0.981	0.029	0.061	0.002	0.0299	0.007
4.	Shadipur	0.204	0.012	0.646	0.029	0.134	0.006	0.0316	0.186
5.	Kasion	0.231	0.014	1.020	0.030	0.025	0.003	0.0481	0.141
6.	Gomat	0.171	0.013	0.856	0.039	0.185	0.013	0.0392	0.642
7.	Dewa Hamidpur	1.920	0.062	0.301	0.044	0.022	0.014	0.0290	1.090
8.	Padam Nagla	0.482	0.060	0.210	0.180	0.153	0.004	0.0318	1.941
9.	Chiti	0.386	0.058	0.981	0.163	0.100	0.003	0.0401	1.860
10.	Pisawan	0.284	0.036	0.894	0.795	0.141	0.018	0.0376	1.424
11.	Edalpur	0.041	0.012	1.860	0.678	0.025	0.017	0.0411	1.316
12.	Khera	0.046	0.012	5.010	0.227	0.472	0.014	0.0298	0.168
13.	Shiwalakalan	0.041	0.049	3.186	0.416	0.213	0.013	0.0298	0.144
14.	Jattari	0.591	0.040	5.048	0.434	0.194	0.006	0.0371	0.759
15.	Bajna	0.306	0.012	5.001	0.061	0.042	0.005	0.0441	1.305
16.	Tappal	0.501	0.029	4.861	0.781	0.186	0.004	0.0477	1.940
17.	Hamidpur	0.464	0.062	2.846	0.784	0.042	0.002	0.0321	1.936
18.	Rasulpur	0.381	0.041	0.086	0.164	0.203	0.010	0.0319	1.231
19.	Untasani	2.681	0.061	4.959	0.129	0.314	0.013	0.0372	1.094
20.	Salpur	2.507	0.032	3.448	0.346	0.061	0.015	0.0423	1.305
21.	Kilpur	2.021	0.041	2.181	0.501	0.095	0.019	0.0420	0.801
22.	Karanpur	1.685	0.024	4.080	0.416	0.101	0.019	0.0408	1.424
23.	Gharbara	1.921	0.014	0.122	0.216	0.501	0.024	0.0416	0.393
24.	Attai	1.396	0.018	0.172	0.041	0.500	0.031	0.0316	0.009
25.	Takpur	0.284	0.015	0.074	0.031	0.286	0.030	0.0313	1.242
26.	Bhagwangarhi	0.046	0.017	0.065	0.081	0.010	0.005	0.0396	1.161
27.	Milhali	0.050	0.058	0.127	0.064	0.105	0.002	0.0366	1.341
28.	Mangarhi	0.890	0.045	0.099	0.044	0.165	0.010	0.0412	1.630
29.	Kulana	0.386	0.031	0.127	0.123	0.113	0.010	0.0321	1.314
30.	Adda	0.181	0.060	1.863	0.024	0.142	0.014	0.0411	1.210
31.	Nojhil	1.167	0.024	1.531	0.041	0.198	0.011	0.0419	1.101
32.	Surir	1.341	0.027	2.406	0.058	0.201	0.012	0.0334	1.401
33.	Nabtauli	1.202	0.020	3.186	0.063	0.115	0.021	0.0333	1.108
34.	Ramnagla	1.011	0.015	1.080	0.101	0.010	0.020	0.0391	1.114
35.	Sultanpur	1.023	0.011	1.121	0.191	0.046	0.003	0.0458	1.131
36.	Jarara	0.081	0.019	1.346	0.637	0.081	0.002	0.0298	1.151
37.	Baraut	0.958	0.008	1.194	0.785	0.099	0.010	0.0356	1.517
38.	Chinpari	0.991	0.006	1.41	0.704	0.184	0.010	0.0317	1.276
39.	Bhairai	1.021	0.019	0.893	0.050	0.155	0.161	0.0316	0.089
40.	Parsauli	0.591	0.043	0.027	0.041	0.136	0.010	0.0313	0.074

APPENDIX - X-B

Trace element data of water samples collected from deep tubewells in the study area
(Results in ppm)

S.No.	Location	Fe	Cu	Zn	Mn	Pb	Cd	Cr	Sr
1.	Sopha	0.230	0.031	1.128	0.057	0.095	0.010	0.0280	1.140
2.	Tapal	0.400	0.018	1.116	0.051	0.198	0.001	0.0414	0.992
3.	Jattari	0.399	0.025	1.126	0.049	0.186	0.004	0.0312	0.755
4.	Nojhil	0.400	0.020	1.127	0.033	0.191	0.011	0.0408	0.991
5.	Surir	0.389	0.021	1.114	0.049	0.161	0.012	0.0313	0.990
6.	Muwaka	0.01	0.001	0.456	0.01	0.002	0.021	0.0286	0.007
7.	Gharbara	0.08	0.006	0.994	0.013	0.008	0.020	0.0407	0.393
8.	Bajna	0.301	0.011	1.123	0.028	0.040	0.002	0.0440	0.992
9.	Padamnagla	0.398	0.028	0.210	0.039	0.121	0.003	0.0310	0.862
10.	Kasison	0.211	0.045	1.010	0.029	0.021	0.001	0.0417	0.141
11.	Pisawau	0.251	0.039	0.868	0.010	0.115	0.015	0.0325	0.898
12.	Khair	0.389	0.048	1.125	0.053	0.190	0.021	0.0423	0.991
13.	Untasani	0.400	0.041	1.109	0.056	0.189	0.012	0.0319	0.941

APPENDIX - XI A

Results of Partial Chemical Analyses of water samples collected from dug wells of the study area during 1993 (June)

(Results in ppm)

S.No.	LOCATION	pH	E.C.*	Co_3^{--}	HCo_3^-	Cl^-	So_4^{--}	Na^+	K^+	Ca^+	Mg^{++}	F^-	T.D.S.	Total Hardness
1.	Khair	7.70	985	8	275	98	129	70	38	45	27	0.07	425	150
2.	Sopha	8.60	884	12	268	305	62	56	20	25	51	0.06	569	441
3.	Shadipur	7.50	1228	15	551	89	59	120	14	28	26	0.04	809	574
4.	Kasison	7.50	1011	40	768	65	127	140	75	46	34	1.34	310	695
5.	Gomat	8.11	665	14	328	49	73	89	58	12	24	1.18	275	150
6.	Jamunka	8.03	2554	42	766	258	150	194	465	50	68	0.32	430	415
7.	Padam Nagla	9.04	458	9	248	47	91	30	53	63	26	0.45	310	169
8.	Chiti	8.73	581	14	330	46	206	48	41	51	43	0.49	276	174
9.	Pisawan	8.98	1202	26	702	51	110	58	8	55	45	0.09	259	228
10.	Edalpur	8.67	2109	26	326	276	408	350	25	54	155	0.07	338	324
11.	Khera	8.15	1451	33	468	198	65	110	130	51	102	1.20	258	518
12.	Shiwalan Khurd	8.08	2553	8	348	249	98	388	181	12	33	1.03	252	155
13.	Bajna	7.74	1011	12	600	156	55	146	68	64	11	1.02	440	490
14.	Jattari	8.48	3029	41	675	433	598	710	18	14	49	0.09	509	667
15.	Tappal	8.20	1198	9	232	90	142	78	29	62	28	1.31	471	299
16.	Hamidpur	8.01	776	11	404	58	54	207	2.0	65	21	1.23	379	350
17.	Untasani	8.10	875	10	156	71	42	66	9	40	20	0.46	444	600
18.	Takipur	8.89	744	34	401	89	89	167	4.0	14	18	1.45	508	171
19.	Bhagwangarhi	8.45	934	18	336	63	55	87	4.98	70	36	1.31	836	339
20.	Nojhil	8.46	1025	10	178	46	163	102	24	45	21	0.41	198	175
21.	Surir	8.01	5080	34	473	1218	100	810	13	85	31	1.22	343	345
22.	Chinpari	8.13	1414	31	523	209	208	140	29	21	103	1.49	302	609
23.	Adda	8.43	1463	28	290	279	112	159	14	74	43	1.10	1011	398
24.	Jarara	9.04	1671	41	776	102	219	244	4.69	22	64	1.89	545	335
25.	Naoli	8.13	1202	29	757	48	185	95	4.80	41	38	1.27	615	1010
26.	Musandgarhi	8.61	2606	40	799	56	138	395	21	25	49	1.81	495	250
27.	Bhairai	8.42	1638	11	76	209	209	158	11	61	69	0.07	350	458
28.	Mañgarhi	8.51	1350	27	440	130	69	195	4.81	16	34	1.50	2080	218
29.	Dajyadpur	7.51	1031	16	153	52	595	309	41	41	31	0.46	501	152
30.	Sultanpur	8.33	3758	26	285	659	141	448	9.5	120	14	0.34	410	911

*E.C. in micro-mhos/cm at 25°C.

APPENDIX - XI B

Concentration of major ions in water samples of observation wells during June, 1993
(Results in epm)

S.No.	LOCATION	pH	E.C.	CO_3^{--}	HCO^-	Cl^-	SO_4^{--}	Na^+	K^+	Ca^{++}	Mg^{++}	Na%	SAR*	Salinity group	R.C.**
1.	Khair	7.70	985	0.26	4.50	2.76	2.68	3.04	0.97	2.24	2.22	47.34	2.04	C_3S_1	0.30
2.	Sopha	8.60	884	0.40	4.39	8.60	1.29	2.43	0.51	1.22	4.19	35.20	1.48	C_3S_1	-
3.	Shadipur	7.50	1228	0.5	9.03	2.50	1.22	5.21	0.35	1.39	2.13	61.23	3.94	C_3S_1	6.01
4.	Kasiscn	7.50	1011	1.33	12.58	1.83	2.64	6.08	1.91	2.29	2.79	61.13	3.82	C_3S_1	8.83
5.	Gomat	8.11	665	0.46	5.37	1.38	1.51	3.86	1.48	0.59	1.97	67.59	3.41	C_2S_1	3.27
6.	Padamnagla	9.04	458	0.30	4.06	1.33	1.89	1.30	1.35	3.15	2.13	33.41	0.80	C_2S_1	-
7.	Jamunka	8.03	2554	1.40	12.55	7.27	3.12	8.43	6.77	2.49	5.59	6.52	4.21	C_4S_1	
8.	Chiti	8.73	581	0.46	5.40	1.29	4.28	2.08	1.04	2.54	3.53	33.94	1.19	C_2S_1	5.87
9.	Pisawan	8.98	1202	0.86	11.50	1.43	2.29	2.52	0.02	2.74	3.70	28.28	1.40	C_3S_1	5.92
10.	Edalpur	8.67	2109	0.86	5.34	7.78	8.49	15.21	0.63	2.69	12.74	50.65	5.49	C_3S_1	-
11.	Khera	8.15	1451	1.10	7.67	5.58	1.35	4.78	3.32	2.54	8.38	42.58	2.05	C_3S_1	-
12.	Shiwala Khurd	8.08	2553	0.26	5.70	7.02	2.04	16.86	4.62	0.59	2.71	86.68	13.17	C_4S_2	2.66
13.	Bajna	7.74	1011	0.40	9.83	4.39	1.14	6.34	1.73	3.19	0.90	66.36	4.43	C_3S_1	6.14
14.	Jattari	8.48	3029	1.36	11.06	12.21	12.45	30.86	0.46	0.69	4.02	86.92	20.16	C_4S_3	7.71
15.	Tappal	8.20	1198	0.30	3.80	2.53	2.95	3.39	0.74	3.09	2.30	43.38	2.06	C_3S_1	-
16.	Hamidpur	8.01	776	0.36	6.62	1.63	1.12	9.00	0.10	3.24	1.72	64.72	5.73	C_3S_1	2.02
17.	Untasani	8.10	875	0.33	2.55	2.00	0.87	2.86	0.23	1.99	1.64	45.98	2.13	C_3S_1	-
18.	Takipur	8.89	744	1.13	6.57	2.50	1.85	7.26	0.10	1.39	1.48	71.94	6.10	C_2S_1	4.83
19.	Bhagwangarhi	8.45	934	0.60	5.50	1.77	1.14	3.78	0.12	3.49	2.96	37.68	2.11	C_3S_1	-
20.	Nojhil	8.46	1025	0.33	2.91	1.29	3.39	4.43	0.61	2.24	1.72	56.0	3.16	C_3S_1	-
21.	Surir	8.01	5080	1.13	7.75	34.34	2.08	35.21	0.33	4.24	2.54	83.97	19.13	C_4S_3	2.1
22.	Chinpari	8.13	1414	1.03	8.57	5.89	4.33	6.08	0.74	1.04	8.47	47.76	2.78	C_3S_1	0.09
23.	Adda	8.43	1463	0.93	4.75	7.86	2.33	6.91	0.35	3.69	3.53	50.13	3.63	C_3S_1	-
24	Jarara	9.04	1671	1.36	12.71	2.87	4.55	10.60	0.11	1.09	5.26	77.04	5.95	C_3S_1	6.72
25	Naoli	8.13	1202	0.96	12.39	1.35	3.85	4.13	0.12	2.04	3.12	45.16	2.58	C_3S_1	8.19
26	Musandgarhi	8.61	2606	1.33	13.09	1.57	2.87	17.17	0.53	1.24	4.02	77.09	0.59	C_4S_2	9.16
27	Bhairai	8.42	1638	0.36	1.24	5.89	4.35	6.86	0.28	3.04	5.67	45.04	3.29	C_3S_1	-
28.	Mangarhi	8.51	1350	0.90	7.21	3.66	1.43	8.47	0.12	0.79	2.79	70.58	6.00	C_3S_1	4.53
29.	Dajyadpur	7.51	1031	0.53	2.50	1.46	12.38	13.43	1.04	2.04	2.54	75.95	8.29	C_3S_1	-
30.	Sultanpur	8.33	3758	0.86	4.67	18.58	2.93	19.47	0.24	5.98	9.37	56.21	7.02	C_4S_1	-

S.A.R.* = Sodium adsorption ratio

R.C.** = Residual carbonate.

APPENDIX - XII-A

Results of partial chemical analysis of the surface water bodies collected from selected stations, during June, 1993

(All Concentration in ppm)

S.No.	Location	pH	E.C. micro-mhos/cm at 25°C	HCO_3^-	Cl^-	SO_4^{--}	Na^+	K^+	Ca^{++}	Mg^{++}	T.D.S.	Total Hardness
Yamuna River												
1.	Maharajpur	7.5	175	120	18	85	15	8.00	26	15	128	85
2.	Untasani	7.8	230	185	14	44	19	11.00	30	10	135	103
3.	Chinpari	8.0	350	195	20	90	23	7.50	29	9	204	105
4.	Ahowa	8.2	310	200	10	75	30	5.50	21	8	108	115
Karwan River												
5.	Dale khurd	7.6	410	175	20	101.25	33	13	40	25	295	213
6.	Khair	6.0	853	230	45	150.00	25	11	38	28	380	205
7.	Bhadera	8.8	887	210	34	120.00	28	15	58	21	410	210
Patwahnala												
8.	Jalalpur	6.9	642	205	60	75.0	16	18	62	44	480	310
9.	Bajna	7.4	985	360	48	33.30	38	17	95	59	478	280
10.	Adda	8.4	773	280	35	85.89	27	12	110	70	485	281
Mat Branch (Upper Ganga canal)												
11.	Shadipur	7.1	553	210	31.61	10	8.00	8.00	40.00	10.0	195	115
12.	Sopha	7.5	285	195	38.56	12	10.54	9.16	35.06	16.30	244	110
13.	Ahrola	8.1	668	230	44.10	15	6.49	6.49	31.18	11.15	880	140
14.	Khera	7.9	778	190	33.40	13	13.89	12.50	38.60	14.60	773	117

APPENDIX - XII-B

Trace elements data (by I.C.P.S.) of the surface water bodies from selected stations

(All results in ppm)

S.No.	Location	Fe	Cu	Pb	Cd	Mn	Cr	Zn	Li
Yamuna river									
1.	Maharajpur	1.68	1.03	0.154	0.04	0.348	0.039	6.61	0.029
2.	Untasani	0.85	1.08	0.148	0.02	0.494	0.045	7.84	0.050
3.	Chinpari	1.23	1.89	0.184	0.06	0.686	0.036	16.10	-
4.	Ahowa	0.95	1.86	0.188	0.03	0.780	0.041	14.84	-
Karwan river									
5.	Dale Khurd	1.82	1.97	0.194	0.05	0.804	0.051	18.04	0.060
6.	Khair	1.80	2.04	0.275	0.03	0.686	0.034	16.09	0.084
7.	Bhadera	0.96	1.74	0.193	0.09	0.586	0.058	13.04	0.039
Patwahnala									
8.	Jalapur	0.75	2.68	0.160	0.02	0.489	0.051	11.23	0.095
9.	Bajna	0.95	2.50	0.359	0.08	0.904	0.061	14.83	0.050
10.	Adda	1.04	2.08	0.187	0.06	0.453	0.034	13.04	0.091
Mat Branch (Upper Ganga Canal)									
11.	Shadipur	0.546	0.326	0.08	0.011	0.084	0.04	6.02	0.02
12.	Sapha	0.680	0.336	0.06	0.006	0.095	0.04	8.15	0.04
13.	Ahrola	0.930	0.386	0.09	0.008	0.024	0.07	5.00	0.01
14.	Khera	0.880	0.295	0.05	0.014	0.036	0.03	4.06	0.05